EUROPIAN STANDARD

EN 50341-1

Overhead electrical lines exceeding AC 45 kV
Part 1: General requirements – Common specifications

October 2001

CENELEC

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Overhead electrical lines exceeding AC 45 kV Part 1: General requirements - Common specifications

Lignes électriques aériennes dépassant AC 45 kV
Partie 1: Règles générales - Spécifications communes

Freileitungen über AC 45 kV
Teil 1: Allgemeine Anforderungen - Gemeinsame Festlegungen

This European Standard was approved by CENELEC on 2001-01-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CENELEC
European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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Foreword

This European Standard was prepared by the Technical Committee CENELEC TC 11, Overhead electrical lines exceeding AC 1 kV (DC 1,5 kV).

The text of the draft was submitted to the Unique Acceptance Procedure and was approved by CENELEC as EN 50341-1 on 2001-01-01.

The following dates were fixed:

- latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2002-05-01
- latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2004-01-01

Annexes designated "normative" are part of the body of the standard.
Annexes designated "informative" are given for information only.
In this standard, annexes E, G, J & K are normative and annexes A, B, C, D, F, H, L, M, N, P, Q & R are informative.

As far as the overhead lines towers are concerned, the designer may refer to prEN 1993-7-1, currently referred to as ENV 1993-3-1, as prepared by TC 250 of CEN, if considered appropriate.

Contents

Introduction

Detailed structure of the standard

The standard comprises three parts:

Part 1: General requirements - Common specifications

This part, also referred to as the Main Body, includes clauses common to all countries. These clauses have been prepared by Working Groups and approved by CLC/TC 11.

The Main Body is available in English, French and German.

Part 2: Index of National Normative Aspects

This index gives the list of all the National Normative Aspects (NNAs) - see signification and contents of NNAs hereafter under "Part 3: National Normative Aspects".

The index is available in English, French and German.

Part 3: National Normative Aspects

The National Normative Aspects (NNAs) reflect national practices. They generally include A-deviations, special national conditions and national complements.

A-deviations:

A-deviations are required by existing national laws or regulations, which cannot be altered at the time of preparation of the standard.

Reference is made to CENELEC Internal Regulations Part 2, definition 3.1.9.

Special national conditions (snc):

Special national conditions are national characteristics or practices that cannot be changed even over a long period, e.g. those due to climatic conditions, earth resistivity, etc.

Reference is made to CENELEC Internal Regulations, Part 2, definition 3.1.7/ 3.1.9.

National complements (NCPTs):

National complements reflect national practices, which are neither A-deviations, nor special national conditions. It has been agreed within CLC/TC 11 that NCPTs should be gradually adapted to the Main Body, aiming at the usual EN standard structure including only a Main Body, A-deviations and special national conditions.

Rules for the numbering of NNAs:

The NNAs are numbered as follows :

AT	Austria	EN 50341-3-1
BE	Belgium	EN 50341-3-2
CH	Switzerland	EN 50341-3-3
DE	Germany	EN 50341-3-4
DK	Denmark	EN 50341-3-5
ES	Spain	EN 50341-3-6
FI	Finland	EN 50341-3-7
FR	France	EN 50341-3-8
GB	Great Britain	EN 50341-3-9
GR	Greece	EN 50341-3-10
IE	Ireland	EN 50341-3-11
IS	Iceland	EN 50341-3-12
IT	Italy	EN 50341-3-13
LU	Luxembourg	EN 50341-3-14 (non existant)
NL	Netherlands	EN 50341-3-15
NO	Norway	EN 50341-3-16
PT	Portugal	EN 50341-3-17
SE	Sweden	EN 50341-3-18
CZ	Czech Republic	EN 50341-3-19
x	xxxx	EN 50341-3-xx, etc.

Language:

The NNAs are published in English and in the national language(s) of the respective country.

1 Scope

This standard applies to overhead electric lines with rated voltages exceeding 45 kV AC and with rated frequencies below 100 Hz.

This standard specifies the general requirements that shall be met for the design and construction of new overhead lines to ensure that the line is suitable for its purpose with regard to safety of persons, maintenance, operation and environmental considerations.

NOTE 1 The extent of the application of this standard by each country in respect of existing overhead lines is subject to the requirements of the National Normative Aspects (NNA) applicable to that country.

NOTE 2 Design and construction of overhead lines with insulated conductors, where internal and external clearances can be smaller than specified in the standard are not included. All other requirements of the standard may be applied to overhead lines with insulated conductors. When necessary, requirements for clearances can be given in the NNAs.

NOTE 3 This part of the standard is applicable for optical Ground Wires (OPGWs) and optical Conductors (OPCONs). However the standard is not applicable to telecommunication systems which are used on overhead transmission lines either attached to the transmission line conductor/earth wire system (for example wraparound,...) or as separate cables supported by the transmission supports for example All Dielectric Self Supporting (ADSS) or for telecommunication equipment mounted on individual transmission line structures. When necessary, requirements can be given in the NNAs.

This standard does not apply to :
- overhead electric lines inside closed electrical areas as defined in HD 637;
- catenary systems of electrified railways.

2 Definitions, symbols and references

2.1 Definitions

For the purposes of this European Standard, the terms and definitions given in the International Vocabulary (IEC 60050) Chapters 441, 466, 471, 601 and 604 and the following apply.

In order to achieve a better understanding of the definition of certain terms used in this standard, some words in the definitions are written in *italics*. The definitions of these words are also given in this subclause.

2.1.1
action
a) force (load) applied to the *(mechanical) system* (direct action).

NOTE An action can be *permanent, variable* or *accidental.*

b) an imposed or constrained deformation or an imposed acceleration caused for example, by temperature changes, moisture variation, uneven settlement or earthquakes (indirect action)

2.1.2
accidental action
action, usually of short duration, which is unlikely to occur with a significant magnitude during the *design working life*

NOTE An accidental action can be expected in many cases to cause severe consequences unless special measures are taken.

2.1.3

bonding conductor

conductor providing *equipotential bonding*

2.1.4

box values

numerical values identified by $\boxed{}$ "box values" are given as indication. Other values may be specified by NCs in NNAs

2.1.5

characteristic resistance

value of mechanical *resistance* calculated using characteristic values of material properties. These values may be obtained from ENV 1992-1-1, ENV 1993-1-1 or ENV 1995-1-1

2.1.6

characteristic value of a material property

value of a material property having a prescribed probability of not being attained in a hypothetical unlimited test series. This value generally corresponds to a specified fraction of the assumed statistical distribution of the particular property of the material. A nominal value is used as the characteristic value in some circumstances

2.1.7

characteristic value of an action

principal representative value of an action. In so far as this characteristic value can be fixed on statistical bases, it is chosen so as to correspond to a prescribed probability of not being exceeded on the unfavourable side during a "*reference period*" taking into account the *design working life* of the *system* and the duration of the *design situation*

2.1.8

clearance

distance between two conductive parts along a string stretched the shortest way between these conductive parts [IEV 441-17-31]

2.1.9

coefficient of variation

ratio of the standard deviation to the mean value

2.1.10

combination of actions

set of *design values of actions* used for the verification of the *structural reliability* for a *limit state* under the *load case*

2.1.11

combination factor for an action

factor used for the determination of the *combination value for an action*

2.1.12

combination value for an action

value associated with the use of *combinations of actions* to take account of a reduced probability of simultaneous occurrence of the most unfavourable values of several independent *actions*. Value obtained by multiplying the *characteristic value of an action* by the *combination factor for an action* or, in special circumstances, by direct determination

2.1.13

component

one of the different principle parts of the overhead electrical line system having a specified *purpose*. Typical components are *supports*, foundations, *conductors*, insulator strings and hardware

2.1.14

conductor (of an overhead line)

one or more aluminium, aluminium alloy, copper, zinc coated or aluminium clad steel wires, or combinations thereof, wrapped together which collectively have the function of conducting an electrical current [IEV 466-01-15: A wire or combination of wires not insulated from one another, suitable for carrying an electric current]

2.1.15

corona

luminous discharge due to ionisation of the air surrounding an electrode caused by a voltage gradient exceeding a certain critical value

NOTE Electrodes may be conductors, hardware, accessories or insulators.

2.1.16

current to earth

current flowing to earth via the *impedance to earth*

2.1.17

design resistance

structural *resistance* associating all structural properties with the respective *design value of the material properties*

2.1.18

design situation

set of physical conditions representing a *reference period* for which the design will demonstrate that the relevant *limit states* are not exceeded

2.1.19

design value of a material property

value obtained by dividing the *characteristic value of a material property* by the *partial factor for the material property* or, in special circumstances, by direct determination

2.1.20

design value of an action

value obtained by multiplying the *characteristic value of an action* by the *partial factor for an action*

2.1.21
design working life
assumed period for which a *structure* is to be used for its intended *purpose* with anticipated *maintenance* but without substantial repair being necessary

2.1.22
dynamic action
action which causes significant acceleration of the *structure* or structural *elements*

2.1.23
earth
term for the earth as a location as well as for earth as a conductive mass, for example types of soil, humus, loam sand, gravel and stone

2.1.24
earth electrode
conductor which is embedded in the *earth* and conductively connected to the *earth*, or a *conductor* which is embedded in concrete, which is in contact with the *earth* via a large surface (for example *foundation earth electrode*)

2.1.25
earth fault
conductive connection caused by a fault between a phase *conductor* of the main circuit and *earth* or an earthed part. The conductive connection can also occur via an arc. Earth faults of two or several phase *conductors* of the same *electrical system* at different locations are designated as double or multiple earth faults

2.1.26
earth fault current
current which flows from the main circuit to *earth* or earthed parts if there is only one *earth fault* point at the fault location (*earth fault* location)

2.1.27
earth potential rise
voltage between an *earthing system* and *reference earth*

2.1.28
earth rod
earth electrode which is generally buried or driven in vertically to a greater depth. For example it can consist of a pipe, round bar or other profile material

2.1.29
earth surface potential
voltage between a point on the earth surface and *reference earth*

2.1.30
earthing
all means and measures for making a proper conductive connection to earth

2.1.31
earthing conductor
conductor which connects that part of the installation which has to be earthed to an *earth electrode* as far as it is laid outside of the soil (*earth wire*) or buried in the soil

2.1.32
earthing system
locally limited *electrical system* of conductively connected *earth electrodes* or *earthing conductors* and of *bonding conductors*, [or metal parts effective in the same way, for example tower footings, armourings, metal cable sheaths]

2.1.33
earth wire
a conductor connected to earth at some or all supports, which is suspended usually but not necessarily above the line conductors to provide a degree of protection against lightning strokes [IEV 466-10-25]

NOTE An earth wire may also contain metallic wires for telecommunication purposes.

2.1.34
effective field strength
square root of the sum of the squares of the three root mean square (r.m.s.) mutually orthogonal components of the field

2.1.35
effect of action
effect of *actions* on structural *elements* for example: internal force, moment, stress, and strain. The design value of the effect of *action* is the total effect of the respective *design values of actions*

2.1.36
electric field
the electric field created in the vicinity of a charged *conductor* is the vector quantified by the electric field strength, E. This quantity is the force exerted by an electric field on a unit charge and is measured in volts per metre (V/m)

2.1.37
element
one of the different parts of a *component*. For example, the elements of a steel lattice tower are steel angles, plates and bolts

2.1.38
equipotential bonding
conductive connection between conductive parts, to reduce the potential differences between these parts

2.1.39
exclusion limit probability of a variable
value of a variable taken from its distribution function and corresponding to an assigned probability of not being exceeded

2.1.40

external clearances

all *clearances* which are not "*internal clearances*". They include those to the ground plane, roads, buildings and installations (if they are permitted by National Statute) and to objects which can be on any of these

2.1.41

failure (structural)

state of a *structure* whose *purpose* is terminated, i.e. in which a *component* has failed by excessive deformation, loss of stability, overturning, collapse, rupture, buckling, etc.

2.1.42

fixed action

action which has a fixed distribution over the *structure* such that the magnitude and direction of the *action* are determined unambiguously for the whole *structure* if this magnitude and direction are determined at one point on the *structure*

2.1.43

foundation earth electrode

conductor which is embedded in concrete and is in contact with the *earth* via a large surface

2.1.44

free action

action which may have any spatial distribution over the structure within given limits

2.1.45

frequently occupied area

area which people will occupy so frequently that risk of simultaneous *earth fault* must be considered (examples: playgrounds, pavements of public roads, close vicinity of residences, etc.)

NOTE Utilities should define these areas.

2.1.46

highest system voltage

highest (r.m.s.) value of voltage which occurs at any time and at any point of the overhead line under normal operating conditions and for which the overhead electrical line shall be designed

2.1.47

horizontal earth electrode

electrode which is generally buried at a low depth. For example it can consist of strip, round bar or stranded *conductor* and can be carried out as radial, ring or mesh *earth electrode* or as a combination of these

2.1.48

impedance to earth of an earthing system

impedance between the *earthing system* and *reference earth*

2.1.49
internal clearance
clearance between phase *conductors* and earthed parts such as steel *structural elements* and *earth wires* and also those between phase *conductors*. Also included are *clearances* to other circuits on the same *support*

2.1.50
limit state (structural)
state beyond which the *structure* no longer satisfies the design performance requirements

2.1.51
load arrangement
identification of the position, magnitude and direction of a *free action*

2.1.52
load case
compatible *load arrangements*, sets of deformations and imperfections considered simultaneously with defined *variable actions* and *permanent actions* for a particular verification

2.1.53
magnetic field
the magnetic field is a vector quantity. The magnetic field strength, H, is expressed in amperes per metre (A/m)

2.1.54
magnetic flux density
the magnetic flux density, also known as the magnetic induction, is the force exerted on a charge moving in the field and has the unit tesla (T). One tesla is equal to 1 $V{\cdot}s/m^2$ or 1 weber per square metre (Wb/m^2)

2.1.55
maintenance
total set of activities performed during the *design working life* of the *system* to maintain its *purpose*

2.1.56
nominal voltage
voltage by which the overhead electrical line is designated and to which certain operating characteristics are referred

2.1.57
optical conductor (OPCON)
conductor containing optical telecommunication fibres

2.1.58
optical groundwire (OPGW)
optical conductor used solely as an *earth wire*. The conductor *component* may be stranded or may be tubular or a combination of both

2.1.59

partial factor for an action

factor depending on the selected *reliability* level, taking in account the possibility of unfavourable deviations from the *characteristic value of actions*, inaccurate modelling and uncertainties in the assessment of the *effects of actions*

2.1.60

partial factor for a material property

factor covering unfavourable deviations from the *characteristic value of material properties*, inaccuracies in applied conversion factors and uncertainties in the geometric properties and the *resistance* model

2.1.61

permanent action

action which is likely to act throughout a given *design situation* and for which the variation in magnitude with time is negligible in relation to the mean value, or for which the variation is always in the same direction (monotonic) until the *action* attains a certain limit value

2.1.62

perturbed/unperturbed electric field

electric field in the vicinity of a conducting object which is "perturbed" by the presence of such object. In this case, for practical purposes, reference may be made to the "unperturbed *electric field*" (i.e., the field that would exist in the absence of the object)

2.1.63

potential grading

influencing of the earth potential, especially the *earth surface potential*, by means of *earth electrodes*

2.1.64

potential grading earth electrode

conductor which due to shape and arrangement is principally used for *potential grading* rather than for establishing a certain resistance to *earth*

2.1.65

project specification

document supplied by the client to the contractor and containing adequate details of all the requirements for materials, design, manufacture and erection for a particular *system* or for a *component* of a line. The Project specification may supplement the requirements of the standard but it shall not relax their technological requirements and it shall not supersede the minimum requirements specified in this standard. It should be reduced to a minimum for each project, i. e. to truly unique or specific details

2.1.66

purpose

function of the *system* (overhead electrical line), i.e. to transmit electrical power between its two ends, or of a part of the system

2.1.67

quasi-static action

dynamic action that can be described by static models in which the dynamic effects are included

2.1.68
radio interference
any effect on the reception of a required radio signal due to an unwanted disturbance within the radio-frequency spectrum. Radio interference is primarily of concern for amplitude-modulated systems (AM radio and television video signals) since other forms of modulation (such as frequency modulation (FM) used for VHF radio broadcasting and television audio signals) are generally much less affected by disturbances that emanate from overhead lines

2.1.69
reduction factor of a three phase line
ratio, *r*, of the *earth fault current* (or earth return current) over the sum of the zero sequence currents in the phase *conductors* of the main circuit

2.1.70
reference earth (remote earth)
those parts of the *earth* outside the influence area of an *earth electrode* or an *earthing system*, where, between any two points, no perceptible voltages due to the current to earth occur

2.1.71
reference period
period taking into account the *design working life* of the *system* or of one of its *elements* and/or of the *characteristic value of an action*

2.1.72
reliability (electrical)
ability of a system to meet its supply function under stated conditions for a given time interval

2.1.73
reliability (structural)
probability that a *system* performs a given *purpose*, under a set of conditions, during a *reference period*. Reliability is thus a measure of the success of a *system* in accomplishing its *purpose*

2.1.74
resistance (structural)
mechanical property of a *component*, of a cross-section or of an *element* of a *structure*, e.g. bending resistance, buckling resistance. Resistance is the capacity to withstand collapse, or any other form of structural *failure*, which may endanger the *safety* of people or have a deleterious effect on the functioning of the *system*

NOTE Resistance against the following effects may require consideration : - loss of equilibrium of the structure or any part of it, considered as a rigid body, - failure by excessive deformation, rupture, or loss of stability of the structure or any part of it, including supports and foundations.

2.1.75
resistance to earth of an earth electrode
electrical resistance of the *earth* between the *earth electrode* and the *reference earth*. In practice this is a pure resistance

2.1.76
return period
mean interval between successive recurrencies of a climatic *action* of at least defined magnitude. The inverse of the return period gives the probability of exceeding the *action* in one year

2.1.77
safety
ability of a *system* not to cause human injuries or loss of lives during its construction, operation and maintenance

2.1.78
security
ability of a *system* to be protected from a major collapse (cascading effect) if a *failure* is triggered in a given *component*. This may be caused by electrical or structural factors

2.1.79
serviceability limit state
state beyond which specified service criteria for a *structure* or structural *element* are no longer met

2.1.80
soil resistivity
specific electrical resistance of the *earth*

2.1.81
sparkover
disruptive discharge

2.1.82
static action
action which does not cause significant acceleration of the *structure* or structural *elements*

2.1.83
step voltage
that part of the *earth potential rise* which can be picked up by a person with a step-width of 1 m, i.e. the current flowing through the human body from foot to foot

2.1.84
strength
mechanical property of a material, usually given in units of stress

2.1.85
structure
organised combination of connected *elements* designed to provide some measure of rigidity

2.1.86
support
general term for different types of *structure* that support the *conductors* of the overhead electrical line

2.1.87
support, angle
suspension or *tension support* used at an angle point of a line

2.1.88
support, section
tension support with or without a line angle serving additionally as rigid point in a line to limit cascading

2.1.89
support, suspension
support equipped with suspension insulator sets

2.1.90
support, tangent
suspension or *tension support* used in straight line

2.1.91
support, tension
support equipped with tension insulator sets

2.1.92
support, terminal (dead-end)
tension support capable of carrying the total conductor tensile forces in one direction

2.1.93
system (mechanical)
set of *components* connected together to form an overhead electrical line

2.1.94
system (electrical)
all items of equipment which are used in combination for the generation, transmission and distribution of electricity

2.1.95
system with isolated neutral
system (electrical) in which the neutrals of transformers, generators and earthing transformers are not intentionally connected to earth, except for high impedance connections for signalling, measuring or protection purposes

2.1.96
system with low-impedance neutral earthing
system (electrical) in which at least one neutral of a transformer, earthing transformer or generator is earthed directly or via an impedance designed such that due to an *earth fault* at any location the magnitude of the fault current leads to a reliable automatic tripping

2.1.97
system with low-impedance neutral or phase earthing
system (electrical) with isolated neutral or resonant earthing, in which in case of a non-self-extinguishing *earth fault* a neutral or phase *conductor* of the main circuit is earthed directly or via low impedance a few seconds after the occurrence of an *earth fault*

2.1.98

system with resonant earthing

system (electrical) in which at least one neutral of a transformer or earthing transformer is earthed via an arc suppression coil and the combined inductance of all arc suppression coils is essentially tuned to the capacitance of the system to earth for the operating frequency

2.1.99

television interference

special case of *radio interference* for disturbances affecting the frequency ranges used for television broadcasting

2.1.100

touch voltage

that part of the *earth potential rise* across the human body from hand to feet (assumed to be at a horizontal distance of 1 m from the exposed part of the installation)

2.1.101

transferred potential

potential rise of an *earthing system* caused by a current to *earth* transferred by means of a connected *conductor* (for example cable metal sheath, pipeline, rail) into areas with low or no potential rise to *reference earth*

2.1.102

ultimate limit state

state associated with collapse, or with other forms of structural *failure* which may endanger the safety of people

NOTE It corresponds generally to the maximum load-carrying resistance of a structure or a structural element.

2.1.103

unavailability

inability of a *system* to accomplish its *purpose*. Unavailability of an overhead electrical line results from structural *failure* or insufficient *electrical reliability* as well as from *failure* due to other unforeseeable events such as landslides, impact of objects, sabotage, defects in material, etc.

2.1.104

unreliability (structural)

complement to (*structural*) *reliability* or the probability of (*structural*) *failure*

2.1.105

variable action

action which is unlikely to act throughout a given *design situation* or for which the variation in magnitude with time is neither negligible in relation to mean value nor monotonic

2.1.106

voltage difference

voltage acting as a source voltage in the touching circuit with a limited value that guarantees the safety of a person when using additional known resistances (for example footwear or standing on surface insulating material)

2.2 List of symbols

Symbol	Signification	References
A	Accidental action	3.4.1
A	Area projected on a plane perpendicular to the wind	4.2.2.3
A_K	Characteristic value of an accidental action	3.4.2
A_K	Characteristic residual conductor tension	4.2.7
A_{ins}	Projected area of an insulator set	4.2.2.4.2
A_{pol}	Projected area of a pole	4.2.2.4.4
A_t	Effective area of the elements of a tower panel face	4.2.2.4.3
A_{tc}	Effective area of the elements of the lattice crossarm face	4.2.2.4.3
A_{tn}	Effective area of the elements of lattice tower panel face n	4.2.2.4.3
a_{so}	Straight line distance between live parts and earthed parts	5.3.5.1
a_{som}	Minimum value of a_{so}	5.3.5.1
b_1, b_2	Width of the lattice tower panel	4.2.2.4.3
C_c	Drag factor for conductors	4.2.2.4.1
C_{cI}	Drag factor for ice covered conductors	4.2.4.2
C_{ins}	Drag factor for insulator sets	4.2.2.4.2
C_{pol}	Drag factor for poles	4.2.2.4.4
C_{tc}	Drag factor for lattice crossarms in a wind perpendicular to the crossarm face	4.2.2.4.3
C_{tn}	Drag factor for lattice tower panel face n	4.2.2.4.3
C_x	Drag factor for component	4.2.2.3
D	Equivalent diameter of ice covered conductors	4.2.4.4
D_{el}	Minimum air clearance required to prevent a disruptive discharge between phase conductors and objects at earth potential during fast front or slow front overvoltages. D_{el} may be either internal when considering conductor to tower structure clearances or external when considering conductor to obstacle clearances.	5.3.5.1

Symbol	Signification	References
D_{pp}	Minimum air clearance required to prevent a disruptive discharge between phase conductors during fast front or slow front overvoltages. D_{pp} is an internal clearance	5.3.5.1
$D_{50Hz\_p\_e}$	Minimum air clearance required to prevent a disruptive discharge at power frequency voltage between a phase conductor and objects at earth potential. $D_{50Hz\_p\_e}$ is an internal clearance.	5.3.5.1
$D_{50Hz\_p\_p}$	Minimum air clearance required to prevent a disruptive discharge at power frequency voltage between phase conductors. $D_{50Hz\_p\_p}$ is an internal clearance.	5.3.5.1
d	Diameter of a conductor	4.2.2.4.1
d	Distance from the top of a pole	7.6.2.2
E	Electric field strength	2.1.36
E	Total value of the effect of actions	-
E_d	Total design value of the effect of actions	3.7.3
F	Action (force or imposed deformation)	3.4.1
F_d	Design value of an action	3.7.2
F_K	Characteristic value of an action	3.4.2
$F_{R,d}$	Design load for the ultimate limit state	7.3.8
$F_{test,\,R}$	Minimum test load	7.3.8
F_T	Characteristic value of an action with a return period T	3.7.2
G	Permanent action	3.4.1
G_K	Characteristic value of a permanent action	3.4.2
G_K	Characteristic value of self weight of conductors, insulators and supports	4.3.11
G_c	Structural resonance factor for conductors or span factor	4.2.2.4.1
G_{ins}	Structural resonance factor for insulator sets	4.2.2.4.2
G_{pol}	Structural resonance factor for poles	4.2.2.4.4
G_q	Gust response factor	4.2.2.3

Symbol	Signification	References
G_t	Structural resonance factor for lattice tower	4.2.2.4.3
G_x	Structural resonance factor for component	4.2.2.3
g	Peak factor for wind	4.2.2.3
H	Reference altitude for determination of air density	4.2.2.2
H	Magnetic field strength	2.1.53
H	Total length of concrete pole	7.6.4
h	Height above ground	4.2.2.1.4
h	Height of the lattice tower panel	4.2.2.4.3
I	Ice load per unit conductor length	4.2.3.3
I_K	Characteristic ice load per unit conductor length	4.2.3.2
I_R	Reference ice load per unit conductor length	4.2.3.2
K_a	Altitude factor	5.3.4
K_g	Gap factor	5.3.5.2
K_{g_sf}	Switching impulse gap factor for the air gap	5.3.5.2
k_T	Terrain factor	4.2.2.1.5
k_g	Wind speed gust factor	4.2.2.1.4
k_1	Reduction factor for minimum clearance	5.4.3
L	Span length	4.2.2.4.1
L	Length of tower leg	7.7.5.3
L_R	Ruling span	4.2.10.1
L_W	Contribution of the weight span	4.2.3.3
L_n	Span length of span n	4.2.2.4.1
n	Number of variable	3.7.4
Q	Variable action	3.4.1

Symbol	Signification	References
Q_{CK}	Characteristic value of actions resulting from conductor tensile forces	4.3.11
Q_I	Force on conductors from ice loads	4.2.3.3
Q_{IK}	Characteristic value of ice action on conductors	4.2.4.1
Q_K	Characteristic value of a variable action	3.4.2
Q_P	Construction and maintenance loads	4.2.6.1
Q_{PK}	Characteristic value of construction and maintenance loads	4.3.11
Q_{WK}	Characteristic value of wind action	4.2.4.1
Q_{Wc}	Wind force on a tangent support	4.2.2.4.1
Q_{Wins}	Wind force on insulator set	4.2.2.4.2
Q_{Wpol}	Wind force on a pole	4.2.2.4.4
Q_{Wt}	Wind force on a lattice tower panel	4.2.2.4.3
Q_{Wtc}	Wind force on a lattice crossarm	4.2.2.4.3
Q_{Wx}	Wind force on any element of the line	4.2.2.3
Q_n	Variable action n	3.7.4
Q_{nK}	Characteristic value of variable action n	3.7.4
Q_o	Background response part	4.2.2.3
Q_l	Dominant variable action	3.7.4
q	Dynamic wind pressure	4.3.2
q_c	Dynamic wind pressure on conductors	4.3.2
q_h	Dynamic wind pressure at height h above ground	4.2.2.2
q_x	Dynamic wind pressure on any element of the supports or insulator sets	4.3.2
R	Structural resistance	-
R_a	Additional electrical resistance	6.2.4.3
R_b	Backflashover rate	5.3.3.5

Symbol	Signification	References
R_d	Structural design resistance	3.7.3
R_k	Characteristic value of the foundation resistance	8.5.2.1
R_{sf}	Shielding failure flashover rate	5.3.3.5
R_x	Resonant response part	4.2.2.3
r	Reduction factor of a three phase line	2.1.69
T	Return period of a climatic action	3.2.2
T_n	Return period of a variable action n	3.7.4
T_o	Initial horizontal tension in a conductor	4.2.7
T_1	Return period for a dominant variable action	3.7.4
T'	Absolute temperature at a reference altitude H	4.2.2.2
t_F	Duration of the fault current	6.2.4.3
U_D	Voltage difference acting as a source voltage in the touching circuit with a limited value that guarantees the safety of a person when using additional known resistances (e.g. footwear, standing surface insulating material)	6.2.4.2
U_E	Earth potential rise	6.2.4.2
U_T	Touch voltage	6.2.4.2
U_{Tp}	Permissible touch voltage, i.e. the voltage across the human body	6.2.4.2
U_{cw}	Co-ordination withstand voltage	5.3.1
U_{rp}	Representative overvoltage	5.3.1
U_{rw}	Required withstand voltage	5.3.1
U_s	Highest system voltage	5.3.2.2
V	Wind speed	4.2.2.1.1
V_{Ih}	Wind speed associated with icing at a height h above ground	4.2.4.3
V_R	Reference wind speed	4.2.2.1.5
$V_{R(II)}$	Reference wind speed at nearby measuring site of category II	4.2.2.1.5

Symbol	Signification	References
V_g	Gust wind speed	4.2.2.1.1
V_h	Wind speed at height h above ground	4.2.2.1.6
V_{mean}	Mean wind speed	4.2.2.1.1
X_K	Characteristic value of a material property	3.7.2
X_d	Design value of a material property	3.7.2
X_{nK}	Characteristic value of a material property n	3.7.3
X_{nd}	Design value of material property n	3.7.3
z_o	Ground roughness parameter	4.2.2.1.4
α	Exponent for the variation of wind speed with height above ground	4.2.2.1.6
α	Reduction factors for ice loads	4.2.10.2
β	Reduction factor for conductor tension	4.2.7
γ	Partial factor	4.2.11
γ_A	Partial factor for an accidental action	3.7.2
γ_C	Partial factor for conductor tensile loads	4.3.11
γ_F	Partial factor for actions	3.7.2
γ_G	Partial factor for a permanent action	3.7.2
γ_I	Partial factor for an ice action	4.2.4.1
γ_M	Partial safety factor for a material property	3.7.2
γ_P	Partial factor for construction and maintenance loads	4.2.11
γ_{Pt}	Partial factor for action on prestressing force	7.6.4
γ_Q	Partial factor for a variable action	3.7.2
γ_{Qn}	Partial factor for a variable action n	3.7.4

Symbol	Signification	References
γ_W	Partial factor for a wind action	4.2.11
ρ	Air density	4.2.2.2
ρ_E	Resistivity of the ground near the surface (Ω.m)	6.2.4.3
ρ_I	Ice density	4.2.4.2
ρ'	Air density corresponding to an absolute temperature T' and a reference altitude H	4.2.2.2
ϕ	Angle of incidence for the critical wind direction	4.2.2.4.1
ϕ	Angle between wind direction and the longitudinal axis of the lattice crossarm	4.2.2.4.3
χ	Solidity ratio of a tower panel	4.2.2.4.3
Ψ	Combination factor for an action	4.2.11
Ψ_I	Combination factor for an ice action	4.2.4.1
Ψ_Q	Combination factor for a variable action	3.4.3
Ψ_{Qn}	Combination factor for variable action n	3.7.4
Ψ_W	Combination factor for a wind action	4.2.4.1

2.3 References

This European Standard incorporates, by either normative or informative reference, provisions from other publications. These references are cited at the appropriate places in the text together with a statement indicating whether the reference is normative in this standard or informative. All references are undated and the latest edition of the publication referred to applies.

The publications are listed hereafter. These references are in accordance with the CEN and CENELEC catalogues and the Catalogue of IEC publications dated 2001.

Reference	Title
EN ISO 1461	Hot dip galvanised coatings on fabricated ferrous products – Specifications and test methods
EN ISO 9001	Quality systems. Model for quality assurance in design, development, production, installation and servicing
EN ISO 9002	Quality systems. Model for quality assurance in production, installation and servicing

Reference	Title
EN ISO 9003	Quality systems. Model for quality assurance in final inspection and test
EN ISO 14713	Protection against corrosion in iron and steel – Zinc and aluminium coatings - Guidelines
EN 10025	Hot rolled products of non alloy structural steels - Technical delivery conditions
EN 10149	Hot-rolled flat products made of high yield strength steels for cold forming
EN 10204	Metallic products. Types of inspection documents
EN 12465	Wood poles for overhead lines – Durability requirements [1)]
EN 12479	Wood poles for overhead lines – Sizes – Methods of measurement and permissible deviations
EN 12509	Wood poles for overhead lines – Test methods – Determination of modulus of elasticity, bending strength, density and moisture content [1)]
EN 12510	Wood poles for overhead lines – Strength grading criteria [1)]
EN 12511	Wood poles for overhead lines – Determination of characteristic values [1)]
EN 12843	Precast concrete masts and poles [1)]
EN 22063	Metallic and other inorganic coatings - Thermal spraying - Zinc, aluminium and their alloys
EN 50182	Conductors for overhead lines - Round wire concentric lay stranded conductors
EN 50183	Conductors for overhead lines - Aluminium-magnesium-silicon alloy wires
EN 50189	Conductors for overhead lines - Zinc coated steel wires
EN 50326	Conductors for overhead lines - Characteristics of greases [1)]
EN 50351	Basic standard for the calculation and measurement methods relating to the influence of electric power supply and traction systems on telecommunication systems [1)]
EN 50352	Limits relating to the influence of electric power supply and traction systems on telecommunication systems [1)]
EN 60071-1	Insulation co-ordination -- Part 1: Definitions, principles and rules (IEC 60071-1)
EN 60071-2	Insulation co-ordination -- Part 2: Application guide (IEC 60071-2)
EN 60305	Insulators for overhead lines with a nominal voltage above 1 kV - Ceramic or glass insulators for a.c. systems - Characteristics of insulator units of the cap and pin type (IEC 60305)
EN 60383-1	Insulators for overhead lines with a nominal voltage above 1 000 V Part 1: Ceramic or glass insulator units for a.c. systems - Definitions, test methods and acceptance criteria (IEC 60383-1)
EN 60383-2	Insulators for overhead lines with a nominal voltage above 1 000 V Part 2: Insulator strings and insulator sets for a.c. systems - Definitions, test methods and acceptance criteria (IEC 60383-2)

[1)] In preparation.

Reference	Title
EN 60433	Insulators for overhead lines with a nominal voltage above 1 000 V - Ceramic insulators for a.c. systems - Characteristics of insulator units of the long rod type (IEC 60433)
EN 60437	Radio interference tests on high-voltage insulators (IEC 60437)
EN 60507	Artificial pollution test on high voltage insulators to be used on a.c. systems (IEC 60507)
EN 60794-1-1	Optical fibre cables -- Part 1-1: Generic specification - General (IEC 60794-1-1)
EN 60794-1-2	Optical fibre cables -- Part 1-2: Generic specification - Basic optical cable test procedures (IEC 60794-1-2)
EN 60865-1	Short circuit currents - Calculation of effects -- Part 1: Definitions and calculation methods (IEC 60865-1)
EN 60889	Hard-drawn aluminium wire for overhead line conductors (IEC 60889)
EN 61232	Aluminium-clad steel wires for electrical purposes (IEC 61232)
EN 61284	Overhead lines - Requirements and tests for fittings (IEC 61284)
EN 61325	Insulators for overhead lines with a nominal voltage above 1 000 V - Ceramic or glass insulator units for d.c. systems - Definitions, test methods and acceptance criteria (IEC 61325)
EN 61395	Overhead electrical conductors - Creep test procedures for stranded conductors (IEC 61395)
EN 61466-1	Composite string insulator units for overhead lines with a nominal voltage greater than 1 000 V -- Part 1: Standard strength classes and end fittings (IEC 61466-1)
EN 61466-2	Composite string insulator units for overhead lines with a nominal voltage greater than 1 000 V -- Part 2: Dimensional and electrical characteristics (IEC 61466-2)
EN 61773	Overhead lines - Testing of foundations for structures (IEC 61773)
EN 61854	Overhead lines - Requirements and tests for spacers (IEC 61854)
EN 61897	Overhead lines - Requirements and tests for Stockbridge type aeolian vibration dampers (IEC 61897)
EN 187200	Sectional Specification: Optical cables to be used along electrical power lines (OCEPL)
ENV 1090-1	Execution of steel structures. General rules and rules for buildings
EUROCODE 1	ENV 1991 : Basis of design and actions on structures ENV 1991-1 : Basis of design ENV 1991-2-1 : Actions on structures ENV 1991-2-4 : Actions on structures. Wind loads
EUROCODE 2	ENV 1992 : Design of concrete structures ENV 1992-1-1 : General rules and rules for buildings ENV 1992-1-3 : General rules. Precast concrete elements and structures ENV 1992-3 : Design of concrete structures. Concrete foundations

Reference	Title
EUROCODE 3	ENV 1993 : Design of steel structures ENV 1993-1-1 : General rules and rules for buildings ENV 1993-1-3 : Supplementary rules for cold formed thin gauge members and sheeting ENV 1993-5 : Piling
EUROCODE 5	ENV 1995 : Design of timber structures ENV 1995-1-1 : General rules and rules for buildings
EUROCODE 7	ENV 1997 : Geotechnical design ENV 1997-1 : General rules
EUROCODE 8	ENV 1998 : Design provisions for earthquake resistance of structures ENV 1998-5 : Foundations, retaining structures and geotechnical aspects
HD 474 S1	Dimensions of ball and socket couplings of string insulator units (IEC 60120)
HD 637	Power installations exceeding 1 kV a.c.
IEC 60038	IEC standard voltages
IEC 60050-441	International Electrotechnical Vocabulary - Chapter 441 - Switchgear, controlgear and fuses
IEC 60050-466	International Electrotechnical Vocabulary - Chapter 466 - Overhead lines
IEC 60050-471	International Electrotechnical Vocabulary - Chapter 471 - Insulators
IEC 60050-601	International Electrotechnical Vocabulary - Chapter 601 – Generation, transmission and distribution of electricity - General
IEC 60050-604	International Electrotechnical Vocabulary - Chapter 604 – Generation, transmission and distribution of electricity - Operation
IEC 60287-3-1	Electric cables - Calculation of the current rating - Part 3-1: Sections on operating conditions - Reference operating conditions and selection of cable type
IEC 60372	Locking devices for ball and socket couplings of string insulator units: Dimensions and tests
IEC 60471	Dimensions of clevis and tongue couplings of string insulator units
IEC/TR 60479-1	Guide to effects of current on human beings and livestock – Part 1: General aspects
IEC/TR 60575	Thermal-mechanical performance test and mechanical performance test on string insulator units
IEC 60652	Loading tests on overhead line towers
IEC 60720	Characteristics of line post insulators
IEC 60724	Short-circuit temperature limits of electric cables with rated voltages of 1 kV (U_m = 1,2 kV) and 3 kV (U_m = 3,6 kV)
IEC 60794-4-1	Optical fibre cables -- Part 4-1: Aerial optical cables for high voltage power lines
IEC 60797	Residual strength of string insulator units of glass or ceramic material for overhead lines after mechanical damage of the dielectric
IEC/TR 60815	Guide for the selection of insulators in respect of polluted conditions

Reference	Title
IEC/TR 60826	Loading and strength of overhead transmission lines
IEC 60909	Short-circuit current calculation in three-phase AC systems
IEC 61109	Composite insulators for a.c. overhead lines with a nominal voltage greater than 1 000 V - Definitions, test methods and acceptance criteria
IEC/TR 61211	Insulators of ceramic material or glass for overhead lines with a nominal voltage greater than 1 000 V - Puncture testing
IEC 61467	Insulators for overhead lines with nominal voltage over 1 000 V - AC power arc tests on insulator sets
IEC/TR 61597	Overhead electrical conductors - Calculation methods for stranded bare conductors
IEC/TR 61774	Overhead lines – Meteorological data for assessing climatic loads
IEC 62219	Formed wire concentric lay overhead electrical stranded conductors[1)]
CISPR 16-1	Specification for radio disturbance and immunity measuring apparatus and methods Part 1: Radio disturbance and immunity measuring apparatus
CISPR 16-2	Specification for radio disturbance and immunity measuring apparatus and methods Part 2: Methods of measurement of disturbances and immunity
CISPR 18-2	Radio interference characteristics of overhead power lines and high voltage equipment -- Part 2: Methods of measurement and procedure for determining limits
CISPR 18-3	Radio interference characteristics of overhead power lines and high voltage equipment -- Part 3: Code of practice for minimising the penetration of radio interferences

3 Basis of design

3.1 General

This clause of the standard provides the basis and the general principles for the structural, geotechnical and mechanical design of overhead lines exceeding AC 45 kV.

The clause should be read in conjunction with Eurocodes 1, 2, 3, 5, 7 and 8. The provisions in this standard supersede the corresponding clauses in the said Eurocodes.

The general principles of structural design are based on the limit state concept used in conjunction with the partial factor method as described in 3.7.

The values of the partial factor for actions and material properties depend on the degree of uncertainty for the loads, resistances, geometrical quantities and design model, and on the type of structure and the type of limit state. Partial factors can also depend on the coordination of strength envisaged for the line.

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1) In preparation.

In principle there are two approaches used to determine numerical values for actions and for partial factors. The first is on the basis of the statistical evaluation of meteorological and experimental data and field observations. This should be done in the framework of a probabilistic reliability theory as described in IEC 60826. A second approach is on the basis of calibration by a long and successful history of construction of overhead lines. For most of the factors proposed in the Eurocodes mentioned above this is the guiding principle.

In practice, the two approaches are used in combination, see Figure 3.1. In particular, a statistical method requires a sufficient set of data. In many cases additional activities to obtain such data will be valuable. Comparison with the traditional design method can be performed, related to the long standing experience of constructing and operating overhead lines mentioned above. From this point of view, the statistical approach can be considered as giving added value to the more traditional/empirical approach and vice versa.

The Empirical approach given in 4.3 is an alternative to the General approach applied regarding actions in 4.2. The Empirical approach incorporates the above mentioned experience of national high voltage regulations, which have existed in some countries since about 1900. Therefore, these regulations can give a good basis for calibration of the empirical method. A countercheck of certain values with data obtained from a statistical analysis of available information should be carried out to confirm and calibrate the design criteria.

Each individual National Committee shall decide which specific national and/or regional requirements are to be employed in the design of overhead lines and also defines their relevant partial factors, see 4.2.11 and 4.3.11, if and as required. The National Committee can further decide to use the Empirical approach in 4.3. Partial factors along with related requirements are stated in the NNAs, thus being decisive. They may also be specified in a Project Specification.

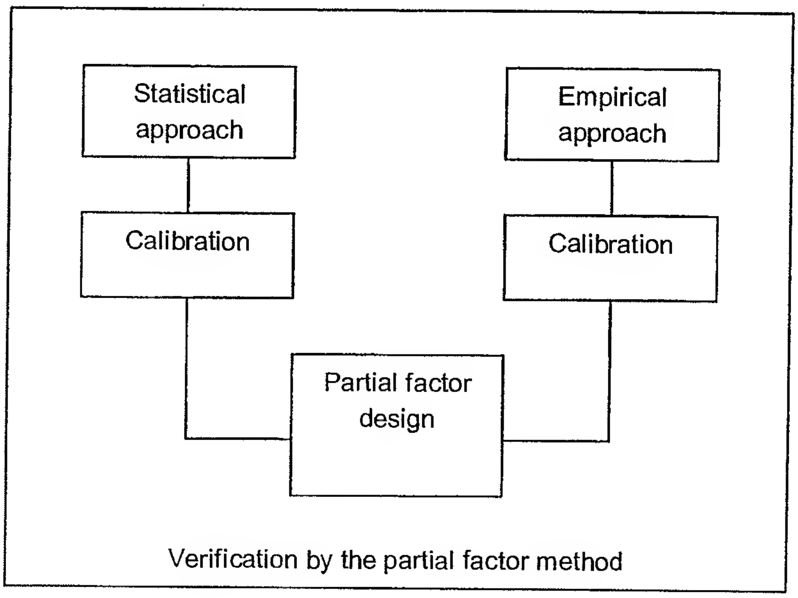


Figure 3.1 - Overview of the determination of partial factors

3.2 Requirements

3.2.1 Basic requirements

An overhead electrical line shall be designed and constructed in such a way that during its intended life,

— it shall perform its purpose under a defined set of conditions, with acceptable levels of reliability and in an economic manner. This refers to aspects of reliability requirements,

— it shall not be liable to a progressive collapse (cascading) if a failure is triggered in a defined component. This refers to aspects of security requirements,

— it shall not be liable to cause human injuries or loss of life during construction and maintenance. This refers to aspects of safety requirements.

An overhead line shall also be designed, constructed and maintained in such a way that due regard is given to safety of the public, durability, robustness, maintainability, environmental considerations and appearance.

The above requirements shall be met by the choice of suitable materials, by appropriate design and detailing, and by specifying control procedures for design, production, construction and use relevant to the particular project.

The selected design situations shall be, by representative load cases, sufficiently severe and varied as to encompass all conditions which can reasonably be foreseen to occur during the construction and the design working life of the overhead line.

3.2.2 Reliability of overhead lines

The reliability required for overhead lines, including all of its components and elements, is achieved by design according to this standard and Eurocodes 1, 2 3, 5, 7 and 8, and appropriate quality assurance measures.

The following a) or b) apply:

a) In accordance with their national experiences and calibrations carried out National Committees can decide to apply one reliability level, generally corresponding at least to reliability level 1 mentioned below. Exceptions to this shall be given in the NNAs.

b) When using the statistical approach, three different reliability levels for overhead lines may generally be considered as defined in Table 3.1, each corresponding to a given return period *T* of the climatic actions.

Table 3.1 – Reliability levels

Reliability level	**Return period T of climatic actions** Years
1	50
2	150
3	500

Deviations from these levels may be made in accordance with the specific requirements for the project in question. However, the level selected shall at least correspond to reliability level 1 except for temporary constructions and for components installed temporarily.

NOTE The yearly reliability of an overhead line is roughly related to the return period *T* of the climatic action and is between 1-1/*T* and 1-1/2*T*, which can be considered as a minimum value. Further information can be found in IEC 60826.

An absolute reliability of an overhead line will generally be difficult to determine. Therefore, reliability level 1 can be regarded as a reference reliability whereas the higher reliability levels are to be understood as relative to the reference one.

Reliability levels, if decided upon, are given in the NNAs.

3.2.3 Security requirements

Security requirements correspond to special loads and/or measures intended to prevent uncontrollable progressive (or cascading) failures.

Should a line fail either due to material defects, unforeseeable events (e.g. impact of an object, landslide, etc.) or an unusual climatic action, it is essential that the failure is contained within or very close to the section where overloads, exceeding the strengths of components, have occurred.

In order to prevent cascading failures, some simulated actions and loading conditions are provided for in this standard as given in clause 4.

A higher level of security may be justified for some overhead lines either due to their importance in the network or because they are subjected to severe climatic loads. In such cases additional measures may be applied for increasing security according to experience and to the type of line to be designed. Insertion of section supports at specified intervals may be adopted to limit a progressive collapse.

3.2.4 Safety requirements during construction and maintenance

Safety requirements are intended to ensure that construction and maintenance operations do not pose safety hazards to people. The safety requirements in this standard consist of special loads, as defined in 4.2.6 and 4.3.6, for which line components (mostly supports) have to be designed.

3.2.5 Coordination of strength

Regarding an overhead line as a system requires coordination of the strength of the components constituting the line. In this standard specific requirements for strength coordination are referred to in the NNAs.

NOTE Strength coordination is in practice generally obtained by matching the partial factors and/or the loading cases.

Annex A gives details of the concept of strength coordination based on IEC 60826.

3.2.6 *Additional considerations*

Consideration of an overhead line as an element in the environment shall take account of the environmental and legal situations existing in a particular region or country.

Safety of human beings and protection of wild life and livestock, for example birds, cattle, etc. shall be properly considered. Specific requirements may be given in NNAs.

3.2.7 *Design working life*

The design working life is the assumed period for which an overhead line is to be used for its intended purpose with anticipated maintenance but without substantial repair being necessary.
The design working life of overhead lines is generally considered to be 50 years, unless otherwise defined in the Project Specification.

NOTE The operating period will normally be in the range of 30 to 80 years.

3.2.8 *Durability*

The durability of a support or part of it in its environment shall be such that it remains fit for use during the design working life given appropriate maintenance.

The environmental, atmospheric and climatic conditions shall be appraised at the design stage to assess their significance in relation to durability and to enable adequate provisions to be made for protection of the materials.

3.2.9 *Quality assurance*

In order to provide an overhead line corresponding to the requirements and to the assumptions made in the design, appropriate quality assurance measures during design and construction shall be adopted.

NOTE Quality assurance is described in EN ISO 9001.

3.3 Limit states

3.3.1 *General*

Limit states are states beyond which the overhead line no longer satisfies the design performance requirements.

Generally, a distinction is made between ultimate limit states and serviceability limit states.

3.3.2 *Ultimate limit states*

Ultimate limit states are those associated with collapse or with other similar forms of structural failure due to excessive deformation, loss of stability, overturning, rupture, buckling, etc.

Damage states prior to structural collapse, which, for simplicity, are considered in place of the collapse itself are also treated as ultimate limit states.

Ultimate limit states concern:

— the reliability and security of supports, foundations, conductors and equipment;

— the safety of people.

3.3.3 Serviceability limit states

Serviceability limit states correspond to certain defined conditions beyond which specified service requirements for an overhead line are no longer met.

The serviceability requirements concern:

— the mechanical functioning of supports, foundations, conductors and equipment;

— the electrical clearances.

Serviceability limit states which may require consideration include:

— deformations and displacements which affect the appearance or effective use of the support including a reduction of electrical clearances;

— vibrations which cause damage to conductors, supports or equipment or which limit their functional effectiveness;

— damage (including cracking) which is likely to affect the durability or the function of the supports, conductors, insulators and line accessories adversely.

Reference should be made to NNAs and the Project Specification for recommendations on serviceability limit states and performance criteria.

3.3.4 Limit state design

Limit state design shall be carried out by:

— setting up structural and load models the for relevant ultimate and serviceability limit states to be considered in the various design situations and load cases;

— verifying that the limit states are not exceeded when design values for actions, material properties and geometrical data are used in the models.

Design values are generally obtained by using characteristic or combination values (as defined in this standard) in conjunction with partial factors as defined in this standard and Eurocodes 2, 3, 5, 7 and 8.

In some cases, it may be appropriate to determine design values directly. The values should be chosen cautiously and should correspond to at least the same degree of reliability for the various limit states as implied in the partial factors in this standard.

3.4 Actions

3.4.1 Principal classifications

An action, *F*, is:

— a direct action, i.e. force (load) applied to the supports including foundations, to the conductors, etc.;

— an indirect action, i.e. an imposed or constrained deformation, caused, for example, by temperature changes, ground water variation or uneven settlement, if applicable.

Actions are classified:

a) by their variation in time:

1) *permanent action (G),* i.e. self-weight of supports including foundations, fittings and fixed equipment.

   Self-weight of conductors and the effects of the applicable conductor tension at the reference temperature, see clause 4, as well as uneven settlements of supports are regarded as permanent actions.

2) *variable actions (Q),* i.e. wind loads, ice loads or other imposed loads.

   Wind loads and ice loads as well as applicable temperatures are climatic conditions which can be assessed by probabilistic methods (reliability concept) or on a deterministic basis.

   Conductor tension effects due to wind and ice and temperature deviations from the reference temperature are variable actions.

   NOTE The vertical reaction from self-weight of the conductor at the support (in other words the weight span) is affected by deviations from the reference state of the conductor tension due to conductor creep and temperature variations. As mentioned, this variation from the reference state is a variable action. Where critical for the design, especially if no other climatic conditions are present, the uncertainty in such a variation -unfavourable or favourable- should be considered by use of a partial factor on the self-weight (or on the weight span).

   Imposed loads arising from conductor stringing, climbing on the structures, etc. are assessed on a deterministic basis and refer to the safety aspect.

3) *accidental actions (A),* i.e. failure containment loads, avalanches, etc. These relate to the security aspect.
   Exceptional ice loads including unbalanced ice loads can be treated as accidental actions if the Empirical approach is employed.

b) by their nature and/or the structural response:

1) *static actions,* which do not cause significant acceleration of the components or elements

2) *dynamic actions,* which cause significant acceleration of the components or elements
   It is usually sufficient to consider the equivalent static effect of quasi-static actions, such as wind loads, in the design of overhead line supports (including foundations). Special attention shall be paid to extraordinary high and/or slender supports.

3.4.2 Characteristic values of actions

The characteristic value of an action, F_K, is its main representative value used for limit state verifications.

Permanent actions (G)

The characteristic value of permanent actions in the design of overhead lines can normally be determined as one value, G_K, as the variability of G is very small.

Variable actions (Q)

For variable actions the characteristic value, Q_K, corresponds to:

— either a nominal value used for deterministic based actions and in the Empirical approach;

— or an upper value with an intended probability of not being exceeded (e.g. wind and ice loads) and in the case of, for example, temperatures, a lower value with an intended probability of not being lower, during a reference period of one year. In this standard a value of probability of 0,02 per year is assumed (i.e. a return period of 50 years).

Accidental actions (A)

For accidental actions the representative value is generally a characteristic value A_K corresponding to a specified value.

3.4.3 Combination values of variable actions

Combination values are associated with the use of combinations of actions, to take account of a reduced probability of simultaneous occurrence of the most unfavourable values of several independent actions.

The combination value of a variable action Q is generally represented as a product of a combination factor and a characteristic value, $\Psi_Q \cdot Q_K$, - or directly by an action with a reduced return period or may be directly specified in clause 4. This combination value ($\Psi_Q \cdot Q_K$) is considered to be the design value. Where the occurrence of actions is correlated with each other, this is reflected in the combination factor.

NOTE In this standard the combination factor for a variable action, Ψ_Q, is principally derived on the basis of a reduced return period and, therefore, includes the partial factor used in the Eurocode format as well as any other reduction factors.

3.5 Material properties

A material property is represented by a characteristic value, which corresponds to that value of the material property having a prescribed probability of not being attained in a hypothetical unlimited test series. It generally corresponds for a particular material property to a specified exclusion limit of the assumed statistical distribution of that material property of the material as used in the system.

A material property value shall normally be determined from standardized tests performed under specified conditions. A conversion factor shall be applied where it is necessary to convert the test results into values, which can be assumed to represent the behavior of the material in the overhead line.

NOTE Material properties specified in Eurocodes 2, 3, 5 and 7 and standards referred to herein may generally be applied if not determined otherwise in this standard. Supplementary information on material data given in IEC 60826 may be adopted as applicable in each case.

3.6 Modelling for structural analysis and resistance

3.6.1 General

Calculations shall be performed using appropriate design models involving relevant variables. The models shall be appropriate to predict the structural behaviour and the limit states considered.

Design models should normally be based on established engineering theory and practice verified experimentally, if necessary.

3.6.2 Interactions between support foundations and soil

Special attention shall be paid to the interaction of:

— loads deriving from the support;

— loads resulting from active soil pressures and the permanent weight of foundation and soil;

— buoyancy effects of ground water on soil and foundation. These, together with the reaction forces of the soil strata shall be taken into account in the calculation of the support foundations.

Also, the limit state criteria for:

— acceptable/unacceptable settlement of the foundation including uneven settlement;

— imposed deformations on the support or support members;

— inclinations of the support (especially angle and dead-end supports);

should be defined and taken into consideration.

Provisions regarding the interaction of loads and recommendations on limit states criteria are given in clauses 7 and 8 including annexes.

3.7 Design values and verification method

3.7.1 General

When following this standard reliability is achieved by the application of partial factors or appropriate return periods for climatic actions based on the statistical approach and partial factors for deterministic actions and material properties.

In the partial factor method it is verified that in all relevant design situations the limit states are not reached when design values for actions, material properties and geometrical data are used in the design models. In particular it shall be verified that

— the effects of design actions do not exceed the design resistance of the overhead line at the ultimate limit state,

— the effects of design actions comply with the performance requirements of the overhead line for the serviceability limit state.

Simplified verifications based on the limit state concept may be used by considering only limit states and load combinations which from experience are known to govern the design.

3.7.2 Design values

The design value of an action, F_d, is expressed in general terms as

$$F_d = \gamma_F \cdot F_K$$

The partial factor for actions, γ_F, depends on the selected reliability level and takes account of the possibility of unfavourable deviations of the actions, inaccurate modelling and uncertainties in the assessment of the effects of actions.

NOTE 1 The design values of the different actions G, Q and A classified in 3.4.1 are calculated as $\gamma_G \cdot G_K$, $\gamma_Q \cdot Q_K$ and $\gamma_A \cdot A_K$, respectively.

NOTE 2 Partial factors for actions are generally based on theoretical considerations, experience and calibration by retrospective calculations on existing designs. National values, stated by National Committees as required, appear in the NNAs, see 3.1.

When calculating the effect of the action on the conductor tension, the partial factors are applied to the characteristic values of the action, i.e. directly on the wind and/or ice action acting on the conductor. The computed value of the conductor tension is then the final design value.

For deterministic calculations including security load conditions the partial factor may, however, be applied to the action effect of the characteristic values of the actions, i.e. on the conductor tension, as specifically mentioned in clause 4 regarding actions.

In the statistical approach the design value of an action, F_d, is determined directly by its value for the selected return period T

$$F_d = F_T$$

The design value of a material property, X_d, is generally defined as

$$X_d = X_K / \gamma_M$$

The partial factor for a material property, γ_M, covers unfavourable deviations from the characteristic value X_K of the material property, inaccuracies in applied conversion factors and uncertainties in the geometric properties and the resistance model. Partial factors for line components are specified in this standard. Partial factors stated in the Eurocodes 2, 3, 5, 7 and 8 generally apply, if not specifically amended in this standard or determined otherwise in the NNAs or Project Specification.

3.7.3 Basic design equation

When considering a limit state of rupture or excessive deformation of a component, element or connection, it shall be verified that

$$E_d \leq R_d$$

where

E_d is the total design value of the effect of actions, such as internal force or moment, or a representative vector of several internal forces or moments, see 3.7.4;

R_d is the corresponding structural design resistance, associating all structural properties with the respective design values, X_{nd}, as follows

$$R_d = f\{X_{1d}, X_{2d}, ...\}$$

or alternatively as defined in each case, the respective characteristic values, X_{nK}

$$R_d = f\{X_{1K}, X_{2K}, ...\}/\gamma_M$$

3.7.4 Combination of actions

Permanent actions G, the values of variable actions Q_1, Q_2, Q_3, etc. which occur simultaneously and accidental actions A as relevant are combined in accordance with the design situation considered.

For each critical load case, the design values of the effects of actions, E_d, should be determined as given by the equations (1) and (3) below.

The alternative equations (2) and (4) apply when the variable actions Q_n are determined directly. In equation (2) the dominant variable action Q_1 with the return period T_1 corresponding to the selected reliability level (e.g. 150 years) is combined with variable actions Q_n (n > 1) which have reduced return periods T_n (e.g. 3 years). In equation (4) the accidental actions A are combined with variable actions Q_n (n ≥ 1) which are present, and all of which have reduced return periods T_n.

a) Design situations related to permanent and variable actions

Design value of the dominant variable action, $\gamma_{Q1} \cdot Q_{1K}$, i.e. normally either wind or ice, and the combination value of other variable actions, $\Psi_{Qn} \cdot Q_{nK}$, - or in symbolic forms:

$$E_d = f\{\Sigma\, \gamma_G \cdot G_K\,,\ \gamma_{Q1} \cdot Q_{1K}\,,\ \Sigma_{n>1}\, \Psi_{Qn} \cdot Q_{nK}\} \quad (1)$$

$$E_d = f\{\Sigma\, \gamma_G \cdot G_K\,,\ Q_{1\,(T1)}\,,\ \Sigma_{n>1}\, Q_{n\,(Tn)}\} \quad (2)$$

b) Design situations related to accidental actions

Design values of accidental actions, $\gamma_A A_K$, together with defined combination values of variable actions, $\Psi_{Qn}.Q_{nK}$, if any present, - or in symbolic forms:

$$E_d = f\{\Sigma\, \gamma_G \cdot G_K\,,\ \gamma_A \cdot A_K\,,\ \Sigma_{n\geq 1}\, \Psi_{Qn} \cdot Q_{nK}\} \quad (3)$$

$$E_d = f\{\Sigma\, \gamma_G \cdot G_K\,,\ \gamma_A \cdot A_K\,,\ \Sigma_{n\geq 1}\, Q_{n\,(Tn)}\} \quad (4)$$

Imposed deformations should be considered where relevant.

4 Actions on lines

4.1 Introduction

The clause on actions on lines is written in two versions in accordance with 3.1 about design methods. The first is called the "General approach" and the second one is called the "Empirical approach".

Each National Committee is responsible for providing climatic data in their NNA which enables the use of one of the two approaches according to 4.2 (General approach) or 4.3 (Empirical approach).

If the NNAs related to 4.2 do not provide sufficient climatic data, the Project Specification shall include such data from available sources to determine a reliable design.

In the case of the Empirical approach, the determination of wind and ice loads and their combinations as given in the NNAs can be assumed to be well established by experience and long-term operation of overhead lines. They constitute a complete design system, especially taking the defined load cases into consideration. Where possible and makes relevant sense, comparisons with the General approach according to 3.1 and 4.2 should be carried out, duly considering the differences in the two approaches.

The General approach is detailed below. For the Empirical approach, see 4.3.

4.2 Actions, General approach

4.2.1 Permanent loads

Self-weight of supports, insulator sets and other fixed equipment and of the conductors resulting from the adjacent spans act as permanent loads. Aircraft warning spheres and similar elements are to be considered as permanent dead loads.

4.2.2 Wind loads

4.2.2.1 Wind speeds

4.2.2.1.1 Field of application

This subclause contains rules for determining design wind loads acting on overhead line components, based on meteorological data. The rules cover support heights up to those as specified in the NNAs. If no requirements are stipulated in the NNA, 60 m is generally acceptable.

Wind speed time averaging periods other than those used in this clause may be defined in the NNA. In such a case wind engineering parameters taking into account the specific periods used, apply as given in the NNA.

When designing overhead lines in the ultimate limit state, the gust wind speed is critical. In this standard it is optional to use the mean wind speed V_{mean} or the gust wind speed V_g as a basis for the extreme wind speed in accordance with the practice within each country. In the following text a common symbol V for the wind speed is used for the different parameters when there is no need to distinguish between the two options.

Annex B gives guidelines for the statistical evaluation of wind speed data for determination of the extreme wind speed.

4.2.2.1.2 Mean wind speed V_{mean}

In this standard mean wind speed V_{mean} is defined as the mean wind speed in m/s over a period of 10 min at a height of 10 m above the ground in relatively open terrain (category II, see Table 4.2.1).

4.2.2.1.3 Gust wind speed V_g

The gust wind speed V_g is a characteristic maximum value of the momentary turbulent wind (in this standard based on the average speed measured over a period of 2 s).

4.2.2.1.4 Turbulence, terrain category and gust factor

Turbulence is observed as variations time wise and space wise of the momentary value of the speed about its mean value. The turbulence intensity is dependent on the terrain. In this standard terrain is divided into four categories expressed by the ground roughness parameter z_0, see Table 4.2.1. A fifth category is added whose wind climate cannot be directly associated with a ground roughness parameter.

The relation between gust wind speed and mean wind speed is expressed by the equation:

$$V_g = k_g \cdot V_{mean}$$

where k_g is the wind speed gust factor. The gust factor is dependent on the measuring periods defined in 4.2.2.1.2 and 4.2.2.1.3 above, the height h above ground and the ground roughness parameter, z_0. With the measuring periods adopted in this standard, the wind speed gust factor can be calculated as follows:

$$k_g = 1 + 2{,}28 / \ln \frac{h}{z_0}$$

4.2.2.1.5 Reference wind speed V_R

The reference wind speed V_R is the wind speed to be taken into account 10 m above ground at the site in question.

In countries where the mean wind speed option is used, the reference wind speed V_R at a site of a given terrain category can be evaluated from the reference wind speed $V_R(II)$ at a nearby measuring site of category II using the formula

$$V_R = k_T \cdot \ln \frac{10}{z_0} \cdot V_R(II)$$

The terrain factor k_T and the ground roughness parameter z_0 can be found in Table 4.2.1.

If the gust wind speed option is used, the best choice is to take the reference wind speed equal to the reference wind speed V_R at a nearby measuring site regardless of terrain category.

Reference wind speeds are given in the NNA. However, where reference data for wind speeds appears to be insufficient for a particular project, other data sources should be used for determination of the extreme wind speed at the site in question.

NOTE In most European countries wind speed maps are being developed for different regions. For regions that are not covered in such maps, meteorological assistance should be sought.

Table 4.2.1 - Terrain factor k_T and ground roughness parameter z_0 for different terrain categories given in Eurocode ENV 1991-2-4

Terrain category	Characteristics of the terrain	k_T	z_0
I	Rough open sea, lakes with at least 5 km fetch upwind and smooth flat country without obstacles	0,17	0,01
II	Farmland with boundary hedges, occasional small farm structures, houses or trees	0,19	0,05
III	Suburban or industrial areas and permanent forests	0,22	0,30
IV	Urban areas in which at least 15% of the surface is covered with buildings with mean height > 15 m	0,24	1,0
V	Mountainous and more complex terrain where the wind may be locally strengthened or weakened	Shall be evaluated separately, possibly by meteorologist	
NOTE Although the terrain categories listed this table are in accordance with Eurocode ENV 1991-2-4, clause 8, some countries may find another selection of terrain categories more useful and giving a better representation for their terrain. This should be specified in the NNAs. Terrain categories III and IV will usually not be applicable to overhead lines but are included to complete the table.			

4.2.2.1.6 Wind speed V_h at arbitrary height h above ground

For overhead line elements at heights up to 10 m the reference wind speed is used directly:

$$V_h = V_R$$

For overhead line elements more than 10 m above ground a wind speed increased according to the logarithmic law is used. For the mean wind speed option this is given by:

$$V_h = \ln\frac{h}{z_0} / \ln\frac{10}{z_0} \cdot V_R = k_T \cdot \ln\frac{h}{z_0} \cdot V_R(II)$$

where

- h is the height above ground,
- k_T is the terrain factor,
- z_0 is the ground roughness parameter.

The relative variation of mean wind speed with terrain category and height above ground can be found in Table 4.2.2 below.

The gust wind speed option should be deduced from the formulae given above and in 4.2.2.1.4 or as otherwise specified in the NNAs.

Table 4.2.2 – Relative variation of mean wind speed with terrain category and height above ground

Terrain category	$V_h/V_R(II) = k_T \ln(h/z_0)$ as function of height above ground										
	10 m	15 m	20 m	25 m	30 m	35 m	40 m	45 m	50 m	55 m	60 m
I	1,17	1,24	1,29	1,33	1,36	1,39	1,41	1,43	1,45	1,46	1,48
II	1,00	1,08	1,14	1,18	1,22	1,24	1,27	1,29	1,31	1,33	1,35
III	0,77	0,86	0,92	0,97	1,01	1,05	1,08	1,10	1,13	1,15	1,17
IV	0,55	0,65	0,72	0,77	0,82	0,85	0,89	0,91	0,94	0,96	0,98

NOTE Alternatively, if defined in the NNA the following power law may be used for calculation of the variation of the wind speed with terrain category and height h above ground as follows

$$V_h = V_R \left(\frac{h}{10}\right)^{\alpha}$$

where the relevant exponents α depending on the terrain category shall be given in the NNA or Project Specification.

4.2.2.2 *Dynamic wind pressure q_h*

The dynamic wind pressure q_h (in N/m^2) at height h above ground is determined by

$$q_h = \frac{1}{2} \rho \cdot V_h^2$$

where

- ρ is the air density, equal to 1,225 kg/m^3 at 15 °C and atmospheric pressure of 1 013 hPa. For other values of temperature and atmospheric pressure, the relevant air density can be calculated or the relative values from Table 4.2.3 may be used,
- V_h is the wind speed in m/s at height h above ground (ref. 4.2.2.1.6).

When the wind is distributed on different sectors, i.e. wind directions, q_h shall be calculated for the sector which gives the highest pressure on the component or element.

NOTE Some countries have, through long experience and thorough investigation, found that certain values of the dynamic wind pressure are representative for their wind climate. In these cases, reference should be made to the NNAs, where such values are given.

Table 4.2.3 - Relative value of air density ρ as a function of altitude and temperature

Temperature	Altitude			
°C	0 m	600 m	1 200 m	1 800 m
- 30	1,18	1,10	1,02	0,95
- 20	1,13	1,05	0,97	0,91
- 5	1,08	1,00	0,93	0,87
5	1,04	0,96	0,90	0,84
15	1,00	0,93	0,86	0,80
30	0,96	0,89	0,83	0,77

NOTE The values in this table are derived from

$$\rho'/\rho = \frac{288}{T'} e^{-1{,}2\cdot10^{-4}H}$$

where

ρ' is the air density corresponding to an absolute temperature T' at an altitude H,

H is the reference altitude in metres for determination of air density,

T' is the absolute temperature in degrees Kelvin at an altitude H.

4.2.2.3 *Wind force on any element of the line*

The value of the force Q_{Wx} due to wind blowing horizontally, perpendicularly to any element of the line, is given by

$$Q_{Wx} = q_h \cdot G_q \cdot G_x \cdot C_x \cdot A$$

where

q_h is the dynamic wind pressure as defined in 4.2.2.2,

G_q is the gust response factor.

If the mean wind speed option is used, G_q can be calculated from the expression in 4.2.2.1.4 as given below and tabled in Table 4.2.4. The ground rough²ness parameter z_0 is given in Table 4.2.1.

$$G_q = k_g^2 = (1 + 2{,}28 / \ln\frac{h}{z_0})^2$$

If the gust wind speed option is used, the gust response factor is equal to 1.

G_x is the structural resonance factor for the structural element being considered.

The structural resonance factor can be calculated following the method given in Eurocode ENV 1991-2-4, clause B.2, and taking into account the calculation of the gust wind speed used in this standard. In the following subclauses simplified figures for conductors, lattice towers and steel poles are given accordingly.

C_x is the drag factor depending on the shape of the element being considered,

A is the area of the element considered, projected on a plane perpendicular to the wind direction.

NOTE In principle G_x is estimated by the expression below where g (peak factor), Q_o (background response part) and R_x (resonant response part) can be calculated using Eurocode ENV 1991-2-4, clause B.2, taking into account the dimension and dynamic characteristics of the component.

$$G_x = \frac{1 + 2g\sqrt{Q_o^2 + R_x^2} \,/\, \ln\dfrac{h}{z_0}}{G_q}$$

When analyzing the global effect on the support and foundation from the wind forces on conductors, the difference in the gust wind responses of the support and the conductor may be taken into account. The overall reduction in the gust wind forces is typically in the range 5 – 15 %, depending on the dimensions and dynamic characteristics of the interactive components. Application rules may be given in the NNAs.

The wind forces on overhead line components shall be calculated as outlined below or alternatively, if specified in NNAs, by using a combined wind factor in place of G_x and G_c.

Table 4.2.4 - Gust response factor G_q

Terrain category	Gust response factor as function of height above ground										
	10 m	15 m	20 m	25 m	30 m	35 m	40 m	45 m	50 m	55 m	60 m
I	1,77	1,72	1,69	1,67	1,65	1,64	1,63	1,62	1,61	1,60	1,59
II	2,05	1,96	1,91	1,87	1,84	1,82	1,80	1,78	1,77	1,76	1,75
III	2,72	2,51	2,38	2,30	2,24	2,19	2,15	2,12	2,09	2,07	2,05
IV	3,96	3,39	3,10	2,92	2,79	2,69	2,62	2,56	2,51	2,46	2,42

4.2.2.4 Wind forces on overhead line components

4.2.2.4.1 Wind forces on conductors

Wind pressure on conductors causes forces transverse to the direction of the line as well as increased tensions in the conductors. From the two adjacent spans the wind force on a tangent support from each sub-conductor is (see Figure 4.2.1):

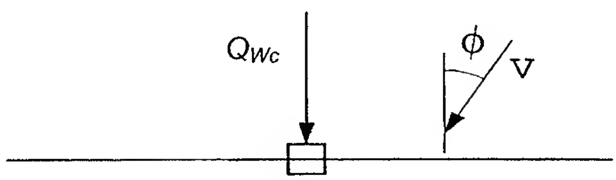


Figure 4.2.1 - Wind force on a tangent support

$$Q_{Wc} = q_h \cdot G_q \cdot G_c \cdot C_c \cdot d \cdot \frac{L_1 + L_2}{2} \cdot \cos^2 \phi$$

where

q_h is the dynamic wind pressure (see 4.2.2.2), calculated corresponding to the centre of pressure on the conductor over the span length,

G_q is the gust response factor (see 4.2.2.3),

G_c is the structural resonance factor for conductors depending on the span length, also termed "span factor". The factor also takes into account the fact that the wind pressure on the conductor in one span does not have its maximum value simultaneously over the whole span.

The span factor can be calculated to give the values in Table 4.2.5 where L is the length of the wind span in metres - or as otherwise specified in the NNAs.

C_c is the drag factor for the conductor.

For round wire stranded conductors and normal design wind speeds, C_c is equal to 1,0. For other types of conductors and for higher wind speeds the value of the drag factor should be measured or calculated.

d is the diameter of conductor,

L_1 and L_2 are the lengths of the two adjacent spans, the mean value of which is the wind span L,

ϕ is the angle of incidence for the critical wind direction.

The total wind force on the bundle of phase conductors is defined as the sum of the forces on the individual sub-conductors, without taking into account possible sheltering effects on leeward conductors.

When considering wind forces on angle supports, the influence of the change in the line direction, the angle of incidence of the wind direction left and right of the angle support as well as the adjacent span lengths and layout of conductors shall be taken into account.

Table 4.2.5 - Span factors G_c

Terrain category	Span factor G_c as function of wind span L						
	Formulae	100 m	200 m	300 m	400 m	600 m	800 m
I	1,30 – 0,073 ln(L)	0,96	0,91	0,88	0,86	0,83	0,81
II	1,30 – 0,082 ln(L)	0,92	0,87	0,83	0,81	0,78	0,75
III	1,30 – 0,098 ln(L)	0,85	0,78	0,74	0,71	0,67	0,65
IV	1,30 – 0,110 ln(L)	0,79	0,72	0,67	0,64	0,60	0,57

NOTE 1 The formulae for G_c are a simplification of the general expression for G_x given in 4.2.2.3. The span factor has been estimated on the basis of a wind front covering the span on both sides of the support.

NOTE 2 For the calculation of the conductor tension a reduction in the effect of the wind pressure due to the section length may be taken into account if the terrain conditions and the conductor height above ground remain the same. In such a case, a span factor based on the section length of the line can be applied.

4.2.2.4.2 Wind forces on insulator sets

Wind forces on insulator sets result from wind forces on the conductors as well as from wind pressure on the insulator sets themselves. The direct wind force is acting on the attachment point on the support in the wind direction and is equal to:

$$Q_{Wins} = q_h \cdot G_q \cdot G_{ins} \cdot C_{ins} \cdot A_{ins}$$

where

- q_h is the dynamic wind pressure (see 4.2.2.2),
- G_q is the gust response factor (see 4.2.2.3),
- G_{ins} is the structural resonance factor for insulator sets, to be taken equal to G_t or G_{pol}, as appropriate,
- C_{ins} is the drag factor for insulator sets, equal to1,2,
- A_{ins} is the area of the insulator set projected horizontally on a vertical plane parallel to the axis of the string.

4.2.2.4.3 Wind forces on lattice towers

Wind forces on lattice towers result from forces transferred from conductors and insulators as well as wind pressures directly on the tower itself.
For lattice towers of rectangular cross-sections, the forces shall be calculated for panel sections according to selected height intervals above the ground. The height of one panel should normally be equal to the distance between two neighbouring joints between the leg member and the bracing member. The wind force acting at the centre of gravity of one panel in a lattice tower with rectangular shape, is:

$$Q_{Wt} = q_h \cdot G_q \cdot G_t \cdot (1+0{,}2 \cdot \sin^2 2\phi) \cdot (C_{t1} \cdot A_{t1} \cdot \cos^2 \phi + C_{t2} \cdot A_{t2} \cdot \sin^2 \phi)$$

where

- q_h is the dynamic wind pressure (see 4.2.2.2),
- G_q is the gust response factor (see 4.2.2.3),
- G_t is the structural resonance factor. For lattice towers below 60 m this shall be taken as 1,05. For structures taller than 60 m, G_t should be evaluated.
- C_{t1} is the drag factor for lattice tower panel face 1 in a wind perpendicular to this panel,
- C_{t2} is the drag factor for lattice tower panel face 2 in a wind perpendicular to this panel,
- A_{t1} is the effective area of the elements of lattice tower panel face 1 (see Figure 4.2.2),
- A_{t2} is the effective area of the elements of lattice tower panel face 2 (see Figure 4.2.2),
- ϕ is the angle between wind direction and longitudinal axis of the lattice cross-arm.

Drag factors, C_t, related to the solidity ratio χ as defined in Figure 4.2.2, are given in Figure 4.2.3 for faces with elements with plane surfaces. For other types of lattice towers drag factors can be found in Eurocode ENV 1991-2-4, clause 10.

For lattice cross-arms, the wind force can be estimated as follows:

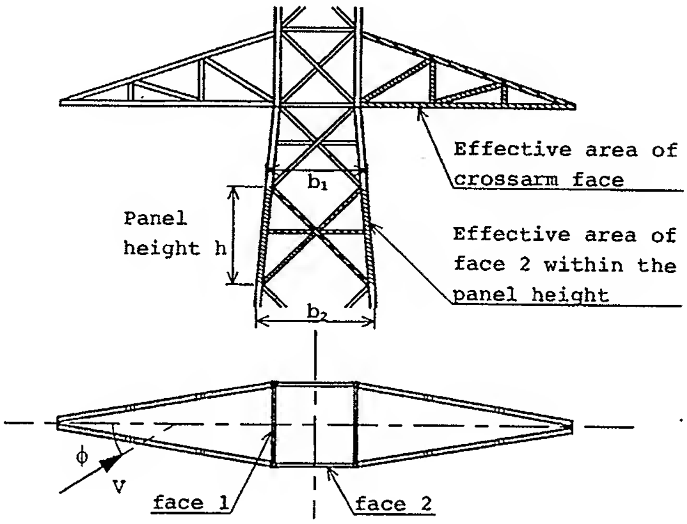
$$Q_{Wtc} = q_h \cdot G_q \cdot G_t \cdot C_{tc} \cdot A_{tc} \cdot (\sin\phi + 0{,}4\cos\phi)$$

where

C_{tc} is the drag factor for the lattice cross-arm in a wind perpendicular to the longitudinal axis of the cross-arm,

A_{tc} is the effective area of the elements of the lattice cross-arm face exposed to the wind (see Figure 4.2.2),

and other parameters are as given above.



$$\chi = A_t \frac{2}{h(b_1 + b_2)}$$

where

χ is the solidity ratio of a tower panel,

A_t is the effective area of elements of a tower panel face projected normal to face. Bracing elements of the adjacent faces and of the diaphragm bracing members can be neglected.

Figure 4.2.2 – Tower panel faces, cross-arm and definition of solidity ratio

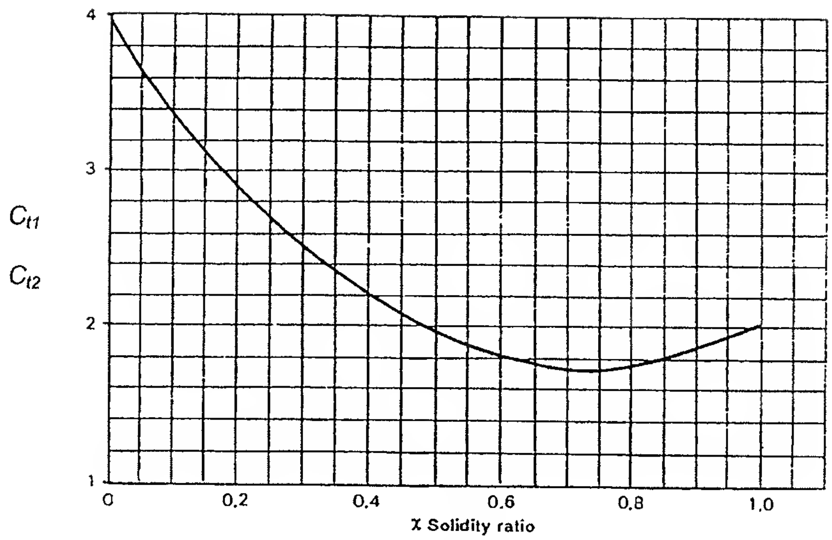


Figure 4.2.3 - Drag factor C_t for a rectangular tower composed of flat sided members

4.2.2.4.4 Wind forces on poles

Wind forces on poles (steel, concrete, wood, etc.) result from wind forces on the conductors and the insulators, as well as wind pressure on the pole itself. The direct wind force is equal to:

$$Q_{Wpol} = q_h \cdot G_q \cdot G_{pol} \cdot C_{pol} \cdot A_{pol}$$

where

- q_h is the dynamic wind pressure (see 4.2.2.2), calculated in appropriate height sections, as necessary,
- G_q is the gust response factor (see 4.2.2.3),
- G_{pol} is the structural resonance factor for a pole, to be evaluated in accordance with 4.2.2.3.
- C_{pol} is the drag factor depending on shape and surface roughness of the pole

  Drag factors can be found in Eurocode ENV 1991-2-4, clause 10. For wood poles 0,8 will be representative.
- A_{pol} is the projected area of the pole.

NOTE For self-supporting steel poles, G_{pol} will typically be 1,15.

4.2.3 Ice loads

4.2.3.1 General

This subclause gives rules for establishing forces on conductors from ice loads, Q_I. As far as applicable, they can also be used for guy wires, etc.

There are two main types of atmospheric ice depending on the process of formation:

— precipitation ice, which can be wet snow or glaze ice;

— in-cloud ice, which can be soft or hard rime.

NOTE Detailed descriptions of the meteorological conditions regarding ice loads are given in IEC 61774.

In areas where both types can occur, it is often difficult to distinguish between them. This is particularly the case in mountain regions, where the most serious icing events often are a combination of the two types. For the two main types mentioned above, the statistical methods which are described in this clause may be used independently.

When determining the design values of ice actions, the influence of the terrain should also be considered when necessary. It is not possible to provide simple and general rules for the terrain effects, but guidance on the influence of local topography for the two main types of atmospheric icing can be found in the IEC report mentioned above.

If there are different climatic and atmospheric conditions along the overhead line, it shall be divided into sections.

Ice loads on other components can be derived from the loadings on conductors, but are not treated especially in this standard.

In most countries statistical ice data is often poor. Therefore, ice loads often have to be specified based directly on experience.

Annex B gives guidelines for the statistical evaluation of ice load data for determination of the extreme ice load.

4.2.3.2 Characteristic ice load

The characteristic ice load per unit length, I_K, (in N/m) to be applied at the site in question is the reference ice load I_R in the different regions of the countries, as specified in NNAs if not otherwise given in the Project Specification.

4.2.3.3 Ice forces on conductors

Ice loads on conductors causes vertical forces as well as increased tensions in the conductors. From the two adjacent spans the vertical ice force on a support from each sub-conductor is

$$Q_I = I(L_{W1} + L_{W2})$$

where

I is the ice load per unit length of the conductor,

Lw_1 and Lw_2 are the contributions of the weight spans of the two adjacent spans.

4.2.4 Combined wind and ice loads

4.2.4.1 Combined probabilities

Only combined wind and ice loads on conductors are considered in this standard. Wind loads on ice covered supports and insulators may be treated similarly when appropriate drag factors are used.

The effect of wind on an ice covered conductor is determined by three variables:

— the wind speed during the period of time that the conductor is ice covered;

— the mass of the ice layer;

— the shape of the ice layer, i.e. the diameter and the relevant drag factor.

In this standard a simplified method is used to determine this effect, taking into account two main combinations:

a) An extreme ice load equal to the design value of the ice load, $\gamma_I \cdot Q_{IK}$, combined with a moderate wind load $\Psi_W \cdot Q_{WK}$. The moderate wind speed associated with ice loads can be taken as 0,55 to 0,65 times the extreme 50 year wind speed depending on the type of ice. Accordingly, a representative value of the combination factor for wind action, Ψ_W, equal to 0,4 has been entered in Table 4.2.8.

b) A high wind speed combined with a moderate ice load, $\Psi_I Q_{IK}$. The high wind speed associated with ice load can be based on a wind speed corresponding to 0,70 to 0,85 times the extreme wind speed used for design, depending on the type of ice. A combination factor for ice action, Ψ_I, equal to 0,35 generally applies and has been entered in Table 4.2.8.

Load combinations and combination factors are given in the NNA, which may include lower wind speeds in accordance with the experience in each country. Further information is given in annex B.

The wind loads according to the different combinations occur in each case simultaneously with the actual ice load (vertical load).

4.2.4.2 Drag factors and ice densities

Table 4.2.6 gives indicative values for the density of various ice types for a range of values of the drag factor. Alternatively, values may be defined in the NNAs.

Table 4.2.6 - Drag factors C_{cI} and density ρ_I (kg/m^3) for various ice types

Ice type	Wet snow	Glaze ice	Soft rime ice	Hard rime ice
C_{cI}	1,0	1,0	1,2	1,1
ρ_I	500	900	300	700

4.2.4.3 Dynamic wind pressure

The dynamic wind pressure (in N/m²) is calculated as in 4.2.2.2:

$$q_h = \frac{1}{2}\rho \cdot V_{Ih}^2$$

where V_{Ih} is the wind speed at a height *h* above ground according to the actual combination as specified in 4.2.4.1.

4.2.4.4 Equivalent diameter D of ice covered conductor

Even if the shape of the ice deposit is rather irregular, it is here assumed as an equivalent cylindrical shape with diameter:

$$D = \sqrt{d^2 + \frac{4I}{9{,}81\pi\rho_I}}$$

where

d	is the conductor diameter (m),
I	is the ice load (N/m) according to the wind combination as specified in 4.2.4.1,
π	is the number 3,141 6,
ρ_I	is the density according to type of ice deposit (kg/m³) and drag factor (see Table 4.2.6).

4.2.4.5 Wind forces on supports from ice covered conductors

Analogous to 4.2.2.4.1 the wind force is generally:

$$Q_{Wc} = q_h \cdot G_q \cdot G_c \cdot C_{cl} \cdot D \cdot \frac{L_1 + L_2}{2} \cdot \cos^2\phi$$

where

q_h	is given in 4.2.4.3,
G_q	is the gust response factor (see 4.2.2.3),
G_c	is the span factor (see 4.2.2.4.1),
C_{cl}	is the drag factor for ice covered conductors given in 4.2.4.2,
D	is given in 4.2.4.4,
L_1 and L_2	are the lengths of the adjacent spans,
ϕ	is the angle of incidence for the critical wind direction.

NOTE 1 For load combinations with moderate wind speeds, the values used for G_c are conservative.

NOTE 2 For the calculation of the conductor tension a reduction in the effect of the wind pressure due to the section length may be taken into account if the terrain conditions and the conductor height above ground remain the same. In such a case, a span factor based on the section length of the line can be applied.

4.2.5 *Temperature effects*

Temperature effects in five different design situations may generally apply as described below. They will depend on the other climatic actions, if any, present.

a) a minimum temperature to be considered with no other climatic action, if relevant.

b) a normal ambient reference temperature assumed for the extreme wind speed condition.

c) a reduced wind speed combined with a minimum temperature condition to be considered, if relevant.

d) a temperature to be assumed with icing. For both of the main types of icing a temperature of 0 °C may be used, if not otherwise specified. A lower temperature should be taken into account in regions where the temperature often drops significantly after a snowfall.

e) a temperature to be used for the combination of wind and ice.

Relevant temperatures and associated design situations are given in NNAs.

4.2.6 *Construction and maintenance loads*

4.2.6.1 *General*

The supports shall be able to withstand all construction and maintenance loads, Q_P, which are likely to be imposed on them with an adequate margin of safety, taking into account working procedures, temporary guying, lifting arrangement, etc. Overstressing of the support should be prevented by specification of allowable procedures and/or load capacities.

National requirements may be defined in the NNAs.

4.2.6.2 *Loads related to the weight of linesmen*

The characteristic erection and maintenance load on cross-arms shall not be less than 1,0 kN acting together with the permanent loads and, as relevant, other imposed loads. In the case of lattice steel structures, these forces shall act at the individual most unfavourable node of the lower chords of one cross-arm face, and in all other cases in the axis of the cross-arms at the attachment point of the conductors.

Where walkways or working platforms are installed, they shall be designed for the maximum loads. Requirements may be given in the NNAs or in the Project Specification.

For all members which can be climbed and are inclined with an angle less than 30° to the horizontal, a characteristic load of 1,0 kN acting vertically in the centre of the member shall be assumed without any other loads. Additional requirements or precautions should be added in case pre-assembling on the ground takes place.

Steps (of any kind) shall be rated for a concentrated characteristic load of 1,0 kN acting vertically at a structurally unfavourable position.

4.2.7 Security loads

Security loads in this standard are specified to give minimum requirements on the torsional and longitudinal resistance of the supports by defining failure containment loads. The loads considered are one-sided release of static tension in a conductor and conventional unbalanced overloads, respectively.

National requirements and calculation rules may be defined in NNAs or Project Specification.

a) Torsional loads

At any one earth wire or phase attachment point, the relevant residual static load, if any, resulting from the release of the tension of a phase conductor or sub-conductor or of an earthwire in an adjacent span shall be applied. Tension release in several sub-conductors or conductors may be considered in the same load case (up to all conductors) for more stringent conditions.

Loads and conductor tensions may be calculated at the normal ambient reference temperature without any wind load or ice load and are the applicable design values. This also applies to all unreleased earth wires or phase conductors. More severe climatic conditions may be specified in the NNAs or Project Specification.

b) Longitudinal loads

Longitudinal loads shall be applied simultaneously at all attachment points.

The loads on the support shall be equal to the unbalanced loads - produced by the tension of conductors in all spans in one direction from the support - when a fictitious overload equal to the self-weight of the conductors (affected by a factor, if required) is considered in all spans in the other direction. Alternatively, the loads may be determined as one-sided release of tension in the conductors as mentioned above under item (a).

Loads and conductor tensions are calculated at the normal ambient reference temperature without any wind load and are final design values. More severe climatic conditions may be specified in the NNAs or Project Specification.

NOTE The load transferred to the support from the conductor will depend on the degree of freedom at the conductor attachment point. For conductors supported by suspension insulator sets of typical length the differential loads will normally be small due to the swing of the string.

c) Mechanical conditions of application

The security loads resulting from case (a) and (b) stated above, for suspension supports, may be calculated taking into account the relaxation of the load resulting from any swing of the insulator sets and the elastic deflection or rotation of the support. The calculation may normally be carried out for the ruling span of the line section.

The security load values (resulting from cases (a) and (b) stated above) may also be limited by devices designed for this purpose (slipping clamps, for instance).

Alternatively, the security load may be determined as a fraction of the conductor tension, as follows

$$A_K = \beta \cdot T_0$$

where

A_K is the characteristic residual conductor tension,

β is the reduction factor for the conductor tension,

T_0 is the initial horizontal tension in the conductor.

Different β-factors may be chosen to cover the different relevant conditions in cases a) and b) mentioned above. A partial factor may be applied on the characteristic residual conductor tension.

4.2.8 Forces due to short-circuit currents

Consideration should be given to the effects of the forces imposed on those overhead lines forming part of a transmission system with very high short circuit characteristics. Information on this subject is given in annex C. National requirements for forces due to short-circuit currents shall be defined in the NNAs or Project Specification, if necessary.

4.2.9 Other special forces

4.2.9.1 Avalanches, creeping snow

When overhead lines are to be routed in or through mountainous regions where they may be exposed to avalanches or creeping snow, consideration shall be given to the possible additional loads which may act on the supports, foundations and /or conductors. Some information on this subject is given in annex C. National requirements shall be defined in the NNAs or Project Specification, if necessary.

4.2.9.2 Earthquakes

When overhead lines are to be constructed in seismically active regions, consideration shall be given to forces on lines due to earthquakes and/or seismic tremors. Some information on this subject is given in annex C. National requirements shall be defined in the NNAs or Project Specification, if necessary.

4.2.10 Load cases

4.2.10.1 General

For the design of conductors, equipment and supports including foundations in the ultimate limit state the load case giving the maximum loading effect in each individual member shall be considered.

In cases where an external load component decreases the stress in a particular member or cross-section, a special load case shall be considered where the load component causing the decrease shall be set to the minimum credible value whilst the other load components remain unchanged.

NOTE 1 An example of the effect mentioned above occurs in the gantry of a horizontal configuration support. The ice load on the middle conductor causes a decrease in the stress in the middle of the gantry, and a load case with minimum ice load in the centre should be considered.
Another example is a guyed support where an eccentricity at the ends of pinned masts is introduced to reduce the bending effects due to wind load on the mast. A loading condition with minimum wind load on the mast should be considered.

Conductor tensions shall be determined according to the loads acting on the conductor in the defined load case. The components of the conductor tension at the attachment points of the support, including the effect of vertical and horizontal angles, shall be taken into account properly. If initially the circuits on a multi circuit support or the sub-conductors of bundles will only be partially installed this condition shall be considered in the design.

NOTE 2 The conductor tension can normally be calculated using the ruling span concept provided that the conductor is suspended by insulator sets allowing the necessary deflections in the longitudinal direction of the line. For reasonably flat terrains, the ruling span L_R is determined by the expression

$$L_R = \sqrt{\frac{\sum L_n^3}{\sum L_n}}$$

where L_n is the length of each individual span of the line section.

Loads on the supports shall be properly selected taking into account defined capacities and intended purpose. Generally, a distinction is made between suspension supports and tension supports. Also a combination of these support types, for example a junction-support, may apply.

Requirements in the NNAs may refer to the above-mentioned support types, as applicable. Further, special supports may be required, for example high crossing supports, for which specific requirements in the Project Specification shall be defined.

4.2.10.2 Standard load cases

For control of adequate reliability and functions under service conditions of the overhead line, load cases including the options given below may be defined in the NNAs in addition to the *standard load cases* specified in Table 4.2.7.

Table 4.2.7 - Standard load cases

Load case	Load as per subclause	Conditions	Remark
1a 1b	4.2.2	Extreme wind load Wind load at a minimum temperature	See (a) If relevant, see 4.2.5
2a 2b 2c 2d	4.2.3	Uniform ice loads on all spans Uniform ice loads, transversal bending Unbalanced ice loads, longitudinal bend. Unbalanced ice loads, torsional bending	 If relevant, see (b) See (c) If relevant, see (d)
3	4.2.4	Combined wind and ice loads	See (e)
4	4.2.6	Construction and maintenance loads	
5a 5b	4.2.7 (a) 4.2.7 (b)	Security loads, torsional loads Security loads, longitudinal loads	Reduced partial factors for material properties may apply as given in clauses 7 and 8.

In all load cases the vertical component of the permanent actions as given in 4.2.1 shall be included. Where permanent actions reduce the effects of other actions such as uplift on a foundation, the minimum value of the permanent action shall be applied, for example minimum allowed ratio of weight-to-wind span.

If applicable and stated in the Project Specification load cases involving short circuit loads or other special loads in accordance with 4.2.8 and 4.2.9, respectively, shall be investigated.

Item (a) to (e) applies as given in Table 4.2.7:

a) A wind direction normal to the line shall be considered and at all other angles which may be critical for the design.

   NOTE A wind direction normal to the line or at 45 ° ("quartering wind") will usually be decisive for the majority of supports. Other directions may also be critical depending on the symmetry of the conductor configuration, line angles, etc.

   As an option, wind load on all spans in one direction from the support resulting in longitudinal loads may be considered in the design of the relevant supports, where this condition is not adequately taken care of by other defined load cases.

b) In load case 2b, a reduced ice load equal to the characteristic ice load multiplied by a reduction factor α on all the conductors on all the cross-arms on one side only of the support shall be investigated. This load case is illustrated in Figure 4.2.4. Where this load condition can be ignored α is defined as 1.

c) In load case 2c, the characteristic ice load on all the conductors in one direction only from all the cross-arms of the support shall be multiplied by a reduction factor α_1 and in the other direction by a reduction factor α_2. This load case is illustrated in Figure 4.2.5.

d) In load case 2d, the characteristic ice load on all the conductors on all the cross-arms on one side only of the support and in one direction of the line only shall be multiplied by a reduction factor α_3. For all remaining conductors, the characteristic ice load shall be multiplied by a reduction factor α_4, thus providing the maximum torsion.

   This load case is illustrated in Figure 4.2.6. The number of unbalanced conductors may be specified otherwise in the NNAs. Where this load condition can be ignored or is otherwise taken care of in the NNA by other defined load cases, α_3 and α_4 are defined as 1.

e) As an option, combined unbalanced wind and ice loads may be considered in the design of the relevant supports where this condition due to the site appears to be reasonable and is not adequately taken care of by other defined load cases. The ice load and/or the wind load is applied on all the conductors in one direction only from all the cross-arms of the support resulting in longitudinal loads.

A non-uniform ice load generally applies up to 3 consecutive spans. However, in the NNAs reduced ice loads on all spans to one side of the support may be required.

NOTE: If not specified in the NNAs the reduction factors mentioned above may be taken as follows:
$\alpha = 0,5$; $\alpha_1 = 0,3$; $\alpha_2 = 0,7$; $\alpha_3 = 0,3$; $\alpha_4 = 0,7$.

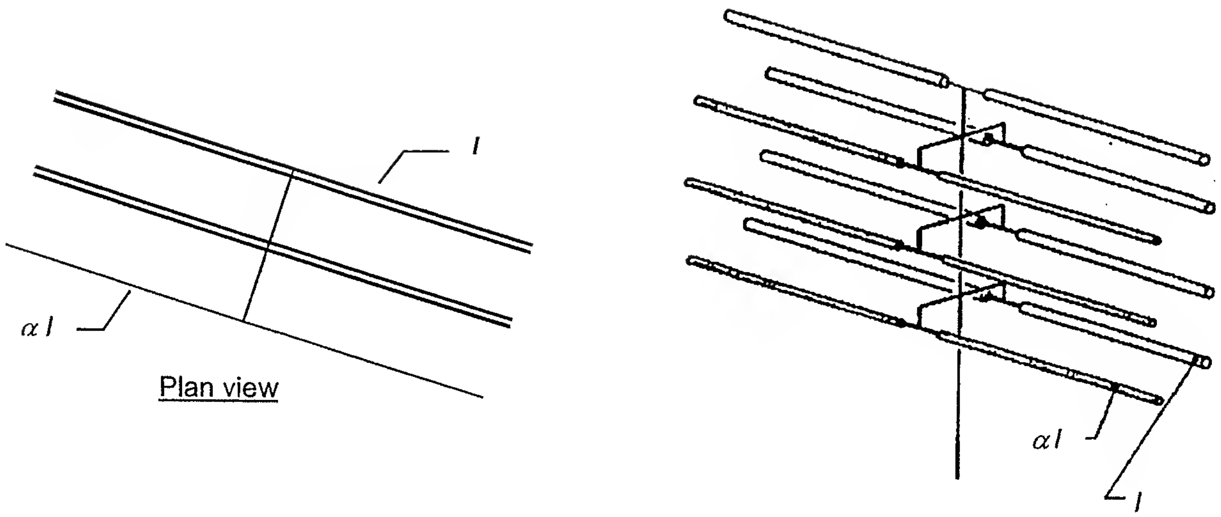


Figure 4.2.4 – Transversal bending

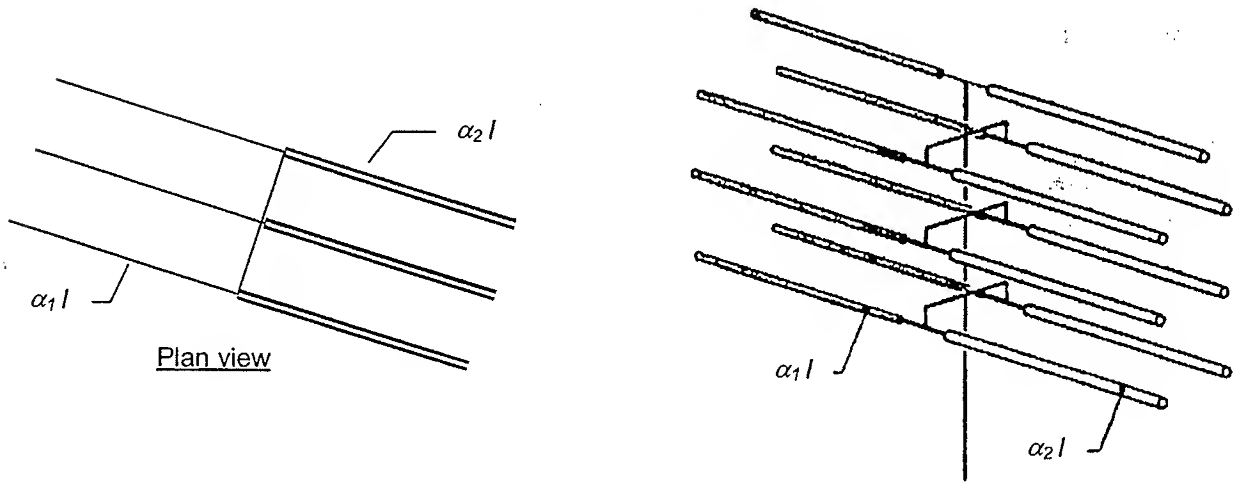
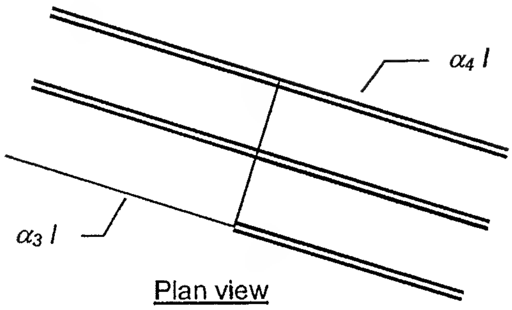


Figure 4.2.5 – Longitudinal bending



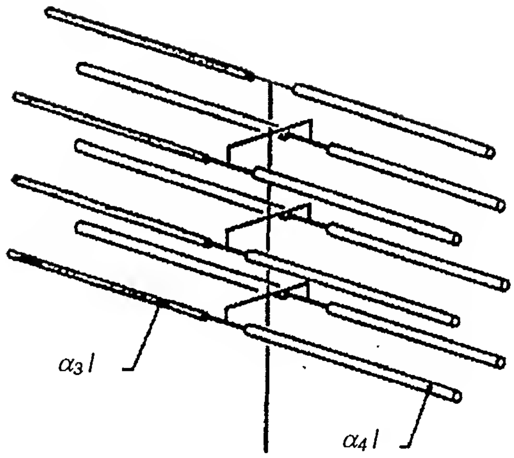


Figure 4.2.6 – Torsional bending

4.2.11 Partial factors for actions

Recommended values of partial factors γ and combination factors Ψ for the actions defined in 4.2.1 to 4.2.10 are given in Table 4.2.8. Modified factors may appear in the NNAs, see 3.1.

Table 4.2.8 - Partial factors and combination factors, ultimate limit states

Action	Symbol	Reliability level		
		1	2	3
Variable actions:				
Climatic loads				
Wind load	γ_W	1,0	1,2	1,4
	Ψ_W	0,4	0,4	0,4
Ice load	γ_I	1,0	1,25	1,5
	Ψ_I	0,35	0,35	0,35
Safety loads				
Construction and maintenance loads [a]	γ_P	1,5		
Permanent actions:				
Self-weight	γ_G	1,0		
Accidental actions:				
Security loads				
Torsional loads due to conductor tension	γ_{A1}	1,0		
Longitudinal loads due to conductor tension	γ_{A2}	1,0		
NOTE The partial factors on actions mentioned above should be considered in conjunction with the partial factors on material properties, which are defined in other clauses of this standard.				
[a] The combination value of wind and ice actions may be taken as the actual forces likely to occur during maintenance and construction. Frequently, the effects of wind and ice actions may be neglected.				

4.3 Actions, Empirical approach

4.3.1 Permanent loads

Refer to 4.2.1. National requirements may be defined in the NNAs.

4.3.2 Wind loads

The wind direction shall be horizontal. The wind force on towers, cross-arms and insulators (generally referred to by subscript *x* and individually by *t*, *tc* and *ins*, respectively),

$$Q_{W\,x} = q_x \cdot C_x \cdot A$$

shall act perpendicularly to the surface exposed to the wind.

For conductors or sub-conductors, the wind force acting perpendicularly to the conductors is given by

$$Q_{W\,c} = q_c \cdot G_c \cdot C_c \cdot d \cdot L \cdot \cos^2 \phi$$

where

q_x is the value for the dynamic wind pressure dependent on the height above ground for supports as given in NNAs. This applies to towers, cross-arms and insulators.

q_c is the value for the dynamic wind pressure dependent on the height above ground for conductors as given in NNAs.

The dynamic wind pressure q (in N/m^2) is equal to

$q = ½\, \rho \cdot V_h^2$

where

ρ is the air density affected by altitude and as a function of temperature and pressure to be expected in the region during wind storms. A recommended value for normal use at 10 °C is: ρ = 1,25 kg/m³. Other values are given in NNAs.

V_h is the wind speed (in m/s) depending on the height above ground and response of structural elements (see NNAs).

G_c is the span factor which can be taken as follows if not otherwise stated in the NNA,

G_c = 1,0	for span lengths up to 200 m,
G_c = 0,6 + 80/L	for span lengths above 200 m.

C_x and C_c are the aerodynamical drag factors which depend on the shape and type of surface of the structural component exposed to wind as defined in NNAs.

A is the projected surface area exposed to wind,

d is the diameter of conductor or sub-conductor or diameter of the additional ice load assumed to be circularly shaped,

L is the span length. When analysing the support the wind span shall be used,

ϕ is the angle of incidence for the critical wind direction.

The wind force on the conductors shall be evaluated with regard to their height above ground at their attachments.

Local conditions shall be especially considered in wind-prone areas.

NOTE For the calculation of the conductor tension a reduction in the effect of the wind pressure due to the section length may be taken into account if the terrain conditions and the conductor height above ground remain the same. In such a case, a span factor based on the section length of the line can be applied.

4.3.3 Ice loads

Forces on conductors from ice loads, Q_I, refer to the ice load per unit length of the conductor as well as other imposed vertical loads, if relevant.

In case of conductors it is necessary to distinguish between "Normal Additional Loads" and "Increased Additional Loads".

An "Increased Additional Load" shall be allowed for if it occurs regularly. It depends on the terrain through which the line runs and may reach many times the Normal Additional Load.

When stipulating the ice loads, the experience with national standards, the observations during the lifetime of other overhead lines and the special topographical and meteorological conditions in the area of the overhead line shall be considered.

National requirements are defined in NNAs.

4.3.4 Combined wind and ice loads

Loads from combined wind and ice forces are considered in 4.3.10. National requirements may be given in NNAs.

4.3.5 Temperature effects

The temperatures present during the occurrence of wind and ice load as well as maximum, minimum and normal ambient reference temperatures shall be considered according to the meteorological conditions. The temperature to be assumed for ice conditions shall be – 5 °C, being the mean value of the temperature range in which icing can occur.

The conductor tensile force shall be determined according to each individual load case. Load cases related to the relevant temperatures are given in 4.3.10.

National requirements may be defined in NNAs.

4.3.6 Construction and maintenance loads

Refer to 4.2.6. National requirements may be given in NNAs.

4.3.7 Security loads

Refer to 4.2.7. National requirements may be given in NNAs.

4.3.8 Forces due to short-circuit currents

Refer to 4.2.8. National requirements may be given in NNAs.

4.3.9 Other special forces

Refer to 4.2.9. National requirements may be given in NNAs.

4.3.10 Load cases

4.3.10.1 General

Refer to 4.2.10.1. National requirements may be given in NNAs.

4.3.10.2 Categories of loads and load cases

Supports shall be rated according to their function and to their appropriate load cases. The load can be subdivided according to the relevant requirements as follows:

— for tower bodies, cross-arms and earthwire peaks;

— normal load cases, construction and maintenance load cases and exceptional, i.e. accidental, load cases;

— torsional loads, cascading and unequal loads shall be calculated separately, but may be summarized as exceptional load cases.

4.3.10.3 Conductor tension load cases

The conductor tensile forces shall be determined according to each individual load case. If not otherwise stated in NNAs, the mechanical loading of conductors is given in Table 4.3.1 below.

Table 4.3.1 - Conductor tension load cases

Load case	Temperature °C	Load	Note
Normal	- 5	Conductor self-weight + normal additional load (respective increased additional load)	(1)
Normal	- 20	Conductor self-weight	(1)
Normal	+15	Conductor self-weight + maximum wind load	(1) , (3)
Normal	+ 40	Conductor self-weight	(1) , (2)

NOTE 1 Details of normal and exceptional load cases may be defined in the relevant NNAs.

NOTE 2 In case of overhead lines for which a high electric current is likely to occur in summer time, a higher conductor temperature shall be considered, for instance + 60 °C. The maximum conductor temperature is defined in the Project Specification.

NOTE 3 Normal ambient reference temperature associated with the wind load as given in NNAs.

4.3.10.4 Standard load cases

Provisions for normal load cases, construction and maintenance load cases and exceptional load cases are given in NNAs.

If applicable and stated in the Project Specification load cases involving forces due to short-circuit currents or other special forces in accordance with 4.3.8 and 4.3.9, respectively, shall be investigated.

4.3.11 Partial factors for actions (see Annex D)

Partial factors in the Empirical approach are generally applied on the effect of actions, for instance on the forces produced (vertical, transverse and longitudinal) in the case of conductor reactions. Load cases combine loads of different origin.

Further, the basic design equations on the basis of 3.7.3 and 3.7.4 are simplified as follows and must be seen in combination with values given in NNAs:

$$E_d = f\,\{\,\gamma_G \cdot G_K\,,\ \gamma_W \cdot Q_{WK}\,,\ \gamma_I \cdot Q_{IK}\,,\ \gamma_C \cdot Q_{CK}\,,\ \gamma_P \cdot Q_{PK}\,,\ \gamma_A \cdot A_K\,\}$$

where

- E_d is the total design value of the effect of actions, see 3.7.3,
- G_K is the characteristic value of self-weight of conductors, insulators and supports,
- Q_{WK} is the characteristic value of wind action as defined in 4.3.2,
- Q_{IK} is the characteristic value of ice action on conductors as defined in 4.3.3,
- Q_{CK} is the characteristic value of actions resulting from conductor tensile forces due to the effects of the temperature variation, wind action and ice action,
- Q_{PK} is the characteristic value of construction and maintenance loads as defined in 4.3.6,
- A_K is the characteristic value of exceptional actions as defined in 4.3.7 (security loads) and as specified in 4.3.10.

The total effects of actions is a combination of the actions stated above.

Partial factors γ_G, γ_W, γ_I, γ_C, γ_P and γ_A allow for:

— reliability aspects;

— combinations of actions;

— strength coordination;

— definition of load cases.

Partial factors take care of normal and exceptional load cases. The values of the partial factors depend on the loading cases and include the combination factors Ψ.

Recommended values of partial factors for the actions defined in 4.3.1 to 4.3.10 are given in Table 4.3.2 below. Modified factors may appear in the NNAs, see 3.1.

Table 4.3.2 - Partial factors for actions, ultimate limit states

Action	Symbol	Partial factor
Normal load case		
- Variable actions	γ_W , γ_I , γ_C	1,3
- Permanent actions		
where unfavourable	γ_G	1,1
where favourable	γ_G	1,0
Construction and maintenance load case		
- Variable actions	γ_P	1,5
- Permanent actions		
Where unfavourable	γ_G	1,1
Where favourable	γ_G	1,0
Exceptional load case		
- Variable actions	γ_W , γ_I , γ_C	1,0
- Accidental actions	γ_A	1,0
- Permanent actions	γ_G	1,0
NOTE The partial factors on actions mentioned above should be considered in conjunction with the partial factors on material properties, which are defined in other clauses of this standard.		

National requirements may be defined in NNAs and supersede the corresponding elements of 4.3.11.

5 Electrical requirements

5.1 Voltage classification

The overhead line shall be capable of withstanding to an acceptable level of reliability its rated power frequency voltage as well as temporary power frequency over voltages, switching impulses and lightning impulses. Actual voltage and insulation levels shall be defined in a Project Specification. The requirements and guidelines given in the following subclauses give guidance to obtain the required generally accepted levels of reliability.

Table 5.1 gives nominal voltages and corresponding highest system voltages.

Table 5.1 - Nominal voltages and corresponding highest system voltages

Nominal voltage (kV)	Highest system voltage (kV)
45	**52**
50	72,5
60	72,5
63	72,5
66	**72,5**
70	82,5
90	100
110	**123**
132	**145**
150	**170**
220	**245**
225	245
275	300
380	**420**
400	420
480	525
700	765
NOTE: Bold figures are according to IEC 60038.	

5.2 Currents

5.2.1 Normal current

The normal current is dependent on the magnitude of the transmitted power and on the operating voltage. The cross-section of the phase conductors shall be chosen so that the design maximum temperature for the conductor material is not exceeded under specified conditions which shall be defined in the NNAs or the Project Specification.

5.2.2 Short-circuit current

The overhead line shall be designed and erected to withstand without damage the mechanical and thermal effects due to the short circuit currents specified in the Project Specification.

The short-circuit can be:
- three-phase;
- phase-to-phase;
- single phase to earth;
- double phase to earth.

Typical values of the duration of the short circuit for design purposes are:

— earth and phase conductors 0,5 s;
— accessories 1,0 s.

However it is important to take into account the actual duration which is dependent on the tripping time of the protection system for the overhead line. Sometimes therefore the duration can be longer or shorter than the above typical values.

Methods for the calculation of the short-circuit currents in three phase a.c. systems are given in IEC 60909 and methods for calculation of the effects of short-circuit current are given in EN 60865-1. Alternatively, methods for calculation may be specified in the NNAs or the Project Specification.

5.3 Insulation co-ordination

5.3.1 General

The principles and rules of insulation co-ordination are described in EN 60071-1 and EN 60071-2. The procedure for insulation co-ordination consists of the selection of a set of standard withstand voltages which characterize the insulation. In the case of an overhead line, this procedure is composed of the following steps:

— determination of the representative overvoltages (U_{rp});
— determination of the co-ordination withstand voltages (U_{cw}) ;
— determination of the required withstand voltages (U_{rw}).

5.3.2 Origin and classification of voltage stresses on overhead lines and evaluation of the representative overvoltages

5.3.2.1 Classification of overvoltages

The voltages and overvoltages stressing the insulation in service are classified as follows:

— continuous power frequency voltages;
— temporary overvoltages;
— slow front overvoltages;
— fast front overvoltages.

Recommendations are given for the evaluation of the representative overvoltages in EN 60071-2, clause 2.

5.3.2.2 Continuous power frequency voltages

The representative continuous power frequency voltage is considered as constant and equal to the highest system voltage (U_s), the highest value of operating voltage which occurs under normal operating conditions at any time and any point in the system. [IEV 601-01-23] (phase to phase voltage).

5.3.2.3 Temporary overvoltages

Temporary overvoltages are oscillatory overvoltages at power frequency at a given location, of relatively long duration, and which are undamped or weakly damped [IEV 604-03-12]. They usually originate from faults, switching operations (i.e. load rejection), resonance conditions, non- linearities (ferro-resonance)

or by a combination of these. The representative overvoltage is a one minute duration voltage at power frequency, but it is generally not considered for the determination of electrical clearances of a line.

5.3.2.4 Slow front overvoltages

Slow front overvoltages can originate from faults, switching operations or distant direct lightning strokes to overhead lines. Slow front overvoltages of importance for overhead lines are earth fault overvoltages, energization and re-energization overvoltages. The representative voltage stress is characterized by:

— the standard switching impulse wave shape (250/2 500 µs),
— a representative amplitude which can be either an assumed maximum overvoltage or deduced from a probability distribution of the overvoltage amplitudes.

5.3.2.5 Fast front overvoltages

Fast front overvoltages of importance for overhead lines are mainly lightning overvoltages due to direct strokes to the phase conductors or backflashovers or, in the lower system voltage range (< 245 kV), voltages induced by lightning strokes to earth close to the line.

The representative voltage stress is characterized by the standard lightning impulse wave shape (1,2/50 µs). The representative amplitude is either given as an assumed maximum or by a probability distribution of peak values. For the purpose of determining air clearances the representative overvoltage to be considered is that which can propagate beyond a few towers from the point of the lightning strike.

5.3.3 Determination of the co-ordination withstand voltage (U_{cw})

5.3.3.1 General recommendations

Recommendations are given for the evaluation of the co-ordination withstand voltages in EN 60071-2, clause 3.

5.3.3.2 Insulation co-ordination for continuous power frequency voltage and temporary over voltages

The continuous power frequency voltage and the temporary overvoltages determine the minimum required insulator string length. The shape of the insulator units shall often be suitable for the site pollution severity.

In directly-earthed-neutral systems with earth fault factors of 1,3 and below, it is usually sufficient to design the insulators to withstand the highest system voltage phase-to-earth.

For higher earth fault factors, and especially in isolated or resonant earthed neutral systems, consideration of the temporary overvoltages may be necessary.

The co-ordination withstand voltage for the continuous power frequency voltage is equal to the highest system voltage for phase-to-phase insulation and is equal to this voltage divided by √3 for phase-to-earth insulation.

The co-ordination short duration withstand voltage is equal to the representative temporary overvoltage.

When contamination is present on the insulation the response of outdoor insulation to power frequency voltages becomes important. For standardisation purposes, qualitatively four levels of pollution are specified. Table 1 of EN 60071-2 gives for each level of pollution an approximate description of some typical corresponding environments. Insulators shall withstand the highest system voltage in polluted conditions continuously with an acceptable risk of flashover. The co-ordination withstand voltages are taken as equal to the representative temporary overvoltages, and the performance criterion is satisfied by choosing a suitable withstand severity for pollution tests in relation to the site pollution severity. Therefore, the long duration power frequency co-ordination withstand voltage should correspond to the highest system voltage for insulation between phases and this value divided by √3 for insulation between phase and earth. The determination of the pollution level on site may be made according to the above mentioned Table 1 of EN 60071-2. For a quantitative evaluation of the site pollution level by measurements information is available in IEC 60815.

5.3.3.3 *Insulation co-ordination for slow front overvoltages*

Slow front overvoltages are one of the factors determining the electrical clearance distances for systems above 245 kV. For some type of insulators (e.g. string insulator units), the insulator fittings can be a critical design feature.

The co-ordination withstand voltage can be assessed either by a deterministic method or by statistical methods which are described in EN 60071-2.

5.3.3.4 *Insulation co-ordination for fast front overvoltages*

The co-ordination withstand voltage to be used shall be taken as higher than or equal to the overvoltage which can propagate beyond a few towers from the point of the lightning strike. If no more accurate means of calculation is available, the phase to earth overvoltage can be taken as the lightning withstand voltage of the insulator strings (the 90 % lightning withstand voltage of the insulator strings $U_{90\%\_ff\_is}$). This is one of the main factors which defines the lightning performance of an overhead line.

5.3.3.5 *Lightning performance of overhead lines*

This performance can be described by the shielding failure flashover rate, R_{sf}, and by the backflashover rate, R_b. It is fixed by operational considerations and depends on the insulation strength of the line and on the following parameters:

— the lightning ground flash density;
— the height of the overhead line;
— the conductor configuration;
— the protection by shield wire (s) ;
— the tower earthing;
— the installation of surge arresters on the overhead line.

Acceptable levels of shielding failure flashover rates and back flashover rates may be defined in the Project Specification.

NOTE Guidance for the calculation of shielding failure flashover (R_{sf}) rates and backflashover rates (R_b) are given in the CIGRE publication n° 63 "Guide to procedures for estimating the lightning performance of transmission lines": Section 4 deals with R_{sf} and section 6 with R_b.

5.3.4 Determination of the required withstand voltage (U_{rw})

The required withstand voltage is determined from the co-ordination withstand voltage taking into account a correction factor associated with atmospheric conditions. The dielectric strength of the line insulation is affected by the altitude above sea level. This effect, which varies to some extent with the air gap length, is accounted for by an altitude factor K_a depending on the value of the co-ordination withstand voltage considered.

$$U_{rw} = U_{cw}/K_a$$

The factor K_a is generally valid for altitudes up to 1 000 m. All the values of K_a are indicated in Table E.4.

5.3.5 Electrical clearance distances to avoid flashover

5.3.5.1 General

Five types of electrical clearances are considered in the present standard (see also 5.4.):

D_{el} Minimum air clearance required to prevent a disruptive discharge between phase conductors and objects at earth potential during fast front or slow front overvoltages. D_{el} may be either internal when considering conductor to tower structure clearances or external when considering a conductor to obstacle clearance.

D_{pp} Minimum air clearance required to prevent a disruptive discharge between phase conductors during fast front or slow front overvoltages. D_{pp} is an internal clearance.

$D_{50Hz\_p\_e}$ Minimum air clearance required to prevent a disruptive discharge at power frequency voltage between a phase conductor and objects at earth potential. $D_{50Hz\_p\_e}$ is an internal clearance.

$D_{50Hz\_p\_p}$ Minimum air clearance required to prevent a disruptive discharge at power frequency voltage between phase conductors. $D_{50Hz\_p\_p}$ is an internal clearance.

a_{som} Minimum a_{so}-value of a line. This is the smallest value of the straight line distance between live parts and earthed parts.

For derivation of D_{el} and D_{pp} it is recommended to use one of the following methods:

— Method described in annex E;

In this case the external clearances defined in 5.4.3 and 5.4.4 are sufficient to achieve safety for the general public. An example using this method is given in 5.3.5.2.

— Method based on experience.

There is good experience in Europe in using the values for D_{el} and D_{pp} given in Table 5.5. When using these values to determine the external clearances according to 5.4.3, special considerations are necessary as specified in 5.3.5.3.

5.3.5.2 *Result of a calculation using method in annex E*

Annex E gives a theoretical method to determine for each type of transient overvoltage (fast front and slow front) and for the power frequency voltage the minimum electrical clearance necessary to provide the required withstand voltage for certain air gap configurations and a given range of atmospheric conditions.

A numerical application of the formulae in annex E is given in Table 5.2 for the general case of conductor to obstacle distances D_{el} (gap factor K_g = 1,3) and phase conductor distances D_{pp} (gap factor K_g = 1,6) necessary to withstand fast front overvoltages due to lightning. This example covers most of the cases which may occur in practice. There are many possible arcing distances, a_{so}, and the corresponding withstand voltages are not the same as the standard impulse voltages given for equipment in EN 60071-1. According to the different possible shapes of insulators and arcing devices, the insulation level of the line needed for this application can take many values, even outside the list of standard impulse withstand voltages given for equipment in EN 60071-1. Therefore, distances are given for all the range of lightning withstand voltage with 50 kV steps.

It is necessary for the designer of the line to confirm that the sum of D_{el} and the safety distance is sufficient to ensure safety for the general public.

Clause F.2, gives examples of calculation of D_{el}, D_{pp} and D_{50Hz}, for different system voltages.

NOTE The gap factor K_g used to calculate the values within the following tables are in each case K_{g_sf}. The value of K_{g_sf} can be reviewed in annex E.

Table 5.2 - Clearances D_{el} and D_{pp} to withstand lightning overvoltages

Lightning withstand voltage $U_{90\%\_ff\_ls}$ of the line insulator strings (kV)	D_{el} (in metres) K_g = 1,3 K_a (1 000 m)	D_{pp} (in metres) K_g =1,6 K_a (1 000 m)
250	0,48	0,54
300	0,58	0,65
350	0,67	0,74
400	0,77	0,85
450	0,85	0,96
500	0,95	1,06
550	1,04	1,17
600	1,14	1,26
650	1,23	1,37
700	1,33	1,47
750	1,41	1,58
800	1,50	1,68
850	1,60	1,79
900	1,69	1,89
950	1,78	2,00
1 000	1,88	2,08
1 050	1,97	2,19
1 100	2,05	2,29
1 150	2,14	2,40
1 200	2,23	2,50
1 250	2,33	2,60
1 300	2,42	2,71
1 350	2,51	2,81
1 400	2,61	2,92
1 450	2,70	3,02
1 500	2,79	3,13
1 550	2,89	3,23
1 600	2,98	3,33
1 650	3,07	3,44
1 700	3,17	3,54
1 750	3,26	3,65
1 800	3,35	3,75
1 850	3,45	3,86
1 900	3,54	3,96
1 950	3,63	4,06
2 000	3,72	4,17
2 050	3,82	4,27
2 100	3,91	4,38
2 150	4,00	4,48

NOTE This table gives numerical values of clearances at 1 000 m of altitude. If the altitude is consistently lower or higher than 1 000 m, the clearance distances can be corrected using the altitude factor given in Table E.4.

A numerical application of the formulae is given by Table 5.3 for the general case of conductor to obstacle distances (gap factor K_{g_sf} = 1,3) and phase conductor distances (gap factor K_{g_sf} = 1,6) necessary to withstand slow front overvoltages due to switching.

Table 5.3 – Clearances D_{el} and D_{pp} to withstand switching overvoltages

Switching overvoltage $U_{2\%\_sf}$ (kV)	D_{el} (in metres) K_g = 1,3 K_a (1 000 m)	D_{pp} (in metres) K_g = 1,6 K_a (1 000 m)
400	0,88	1,02
450	1,01	1,18
500	1,14	1,32
550	1,29	1,49
600	1,44	1,67
650	1,59	1,86
700	1,73	2,06
750	1,90	2,24
800	2,07	2,45
850	2,25	2,67
900	2,44	2,91
950	2,64	3,15
1 000	2,84	3,41
1 050	3,02	3,68
1 100	3,24	3,96
1 150	3,47	4,26
1 200	3,71	4,57
1 250	3,96	4,90
1 300	4,22	5,24
1 350	4,49	5,60
1 400	4,77	5,97
1 450	5,06	6,36
1 500	5,37	6,78
1 550	5,69	7,21
1 600	6,02	7,66
1 650	6,37	8,14
1 700	6,73	8,63
1 750	7,11	9,16
1 800	7,50	9,70

NOTE This table gives numerical values of clearances at 1 000 m of altitude. If the altitude is consistently lower or higher than 1 000 m, the clearance distances can be corrected using the altitude factor given in Table E.4.

The minimum electrical clearance to be used is the greater of the two distances calculated to withstand lightning and switching overvoltages.

The electrical clearances to withstand power frequency voltage are only for the internal clearances to be used in extreme wind conditions. The numerical application of the formulae in annex E for $D_{50Hz\_p\_e}$ with a gap factor K_g = 1,45 and $D_{50Hz\_p\_p}$ with a gap factor K_g = 1,6 is given in Table 5.4.

Table 5.4 - Minimum electrical clearance distances in air necessary to withstand the power frequency voltage (to be used in extreme wind conditions)

Highest system voltage U_S (kV)	$D_{50Hz\_p\_e}$ (in metres) $K_g = 1,45$ conductor-structure	$D_{50Hz\_p\_p}$ (in metres) $K_g = 1,60$ conductor to conductor
52	0,11	0,17
72,5	0,15	0,23
82,5	0,16	0,26
100	0,19	0,30
123	0,23	0,37
145	0,27	0,42
170	0,31	0,49
245	0,43	0,69
300	0,51	0,83
420	0,70	1,17
525	0,86	1,47
765	1,28	2,30

All these minimum electrical clearance distances are solely based on insulation co-ordination requirements. Other requirements may result in substantially larger clearances. Other values shall be specified in the NNAs together with an explanation of their derivation.

5.3.5.3 Empirical method

The values given in Table 5.5 are based on an analysis of commonly used European values, which have been proved to be sufficient to achieve safety for the general public.

Table 5.5 - Clearances D_{el} and D_{pp}

Highest system voltage U_s (kV)	D_{el} (in metres)	D_{pp} (in metres)
52	0,60	0,70
72,5	0,70	0,80
82,5	0,75	0,85
100	0,90	1,05
123	1,00	1,15
145	1,20	1,40
170	1,30	1,50
245	1,70	2,00
300	2,10	2,40
420	2,80	3,20
525	3,50	4,00
765	4,90	5,60

When using these values for the specification of external clearances it shall be verified that the calculated distance to a person or an object is greater than 110% of a_{som} just at the time that an overvoltage occurs. In most of the cases probability considerations achieve this. The NNAs may define it in more detail.

5.4 Internal and external clearances

5.4.1 Introduction

The internal and external clearances, as given in Tables 5.4.3 and 5.4.4, are determined from a technical point of view and it is accepted that National Statutes may use different values (both higher and lower) and these shall be specified in the NNAs.

The internal clearances given are solely for the purpose of designing for an acceptable ability to withstand overvoltages. (It is accepted in EN 60071-2 and EN 60071-1 that the economic design of a power network will have a limited number of flashovers across some of the critical internal clearances such as those between the conductors and the tower). The purpose of the external clearances is to avoid danger of flashover to the general public, to persons undertaking work in the vicinity of the power lines and to persons maintaining the power network. The clearances given in this subclause are not applicable to those maintaining the overhead line by live line working methods, to whom special rules shall be applied (see 5.4.2.1).

The clearances relate to transmission lines which use bare conductors. Lines which use a solid insulating layer around the phase conductor to prevent a fault caused by a temporary contact to an earthed object or a temporary contact between phase conductors are not covered by this standard.

It is also accepted that to produce economical designs of transmission networks the designer has to optimise the design for a foreseeable range of climatic conditions such as wind speeds and ice loading. Exceptional meteorological events occur and in these circumstances it is considered acceptable that the clearances in this clause shall not be applied. In these exceptional conditions safety of persons is paramount and alternative means shall be sought to ensure this. It is considered that exceptional in this context is once in more than 50 years.

Higher values for minimum clearances may be given in Project Specifications. These values will overrule those in the standard and its annexes. The clearances shall be checked according to load conditions in 5.4.2.2.

When the clearance distance is not specified as "horizontal" or "vertical" it shall be taken as the smallest the distance between the live parts and the object under consideration.

5.4.2 General considerations and load cases

5.4.2.1 General considerations and underlying principles

Clearance distances during live working are not considered in this standard. The subject of clearances for live working are considered and will be recommended by IEC TC 78 and CENELEC TC 78.

The approach taken in this subclause is as follows:

a) There is a basic electrical distance, D_{el}, which prevents the flashover of the live parts to objects at earth potential (external clearances) under normal system operation. (Normal operation includes switching operations, lightning surges and overvoltages resulting from system faults). For internal clearances it is permitted to use lower values than D_{el} because this affects only the reliability of the network. For external clearances D_{el} shall be used.

   There is a further basic electrical distance, D_{pp}, which prevents flashover between phases during switching and lightning overvoltages and this is close to the minimum clearance to be used between phases when the power lines are not affected by adverse weather. For internal clearances it is permitted to use lower values than D_{pp} because this affects only the reliability of the network.

b) An additional clearance is necessary to ground or buildings etc. which is intended to ensure that no person or conductive object enters the electrical distance D_{el} even when they are undertaking work or leisure activities which can be foreseen as reasonably likely.

c) The internal clearances to earthed objects during infrequent events, such as those caused by the maximum swing of the conductors due to wind loading, can be less than those in "a)" above because there is a low probability of a coincident transient overvoltage and this would in any event result only in a supply interruption and present no danger to persons.

   Similarly the clearances between phases during infrequent events, such as those caused by the maximum swing of the conductors due to wind loading, can be less than those in "a)" above because there is a low probability of a coincident transient overvoltage and this would in any event result only in a supply interruption and present no danger to persons.

d) With very long insulator strings, the risk of flashover must always be on the internal distance a_{som} and not to any external object or person.

5.4.2.2 Load cases for calculation of clearances

5.4.2.2.1 Maximum conductor temperature

All vertical clearances shall be based on the maximum continuous service temperature of the conductors specified in the NNAs or in the Project Specification.

NOTE Countries may wish to consider short duration higher temperature loading and reduced clearances in these cases. Requirements should be given in NNAs or the Project Specification.

5.4.2.2.2 Ice load for determination of electrical clearance

The characteristic ice load to be applied shall be specified directly based on the experience of each country. Indications are given in 4.2 (General approach), 4.3 (Empirical approach) and annex B. National requirements shall be defined by NNAs.

5.4.2.2.3 Wind load for determination of electrical clearances

Three cases are to be considered:
— still air;
— wind load for a three year return period;
— wind load for a 50 year return period for gust conditions, in which simultaneous occurrence of a transient overvoltage is considered to be acceptably small.

Indications are given in 4.2 (General approach), 4.3 (Empirical approach) and annex B.

Under wind loading the temperature of a conductor will decrease. The reduction of temperature is dependent on electrical loading, wind speed, wind direction, ambient temperature, etc. The designer may take these circumstances into account while calculating the actual position of the conductor. National requirements shall be defined by NNAs.

The following shall be applied when considering internal and external clearances:

— Under still air conditions the internal clearances shall be greater than or equal to D_{el} or D_{pp}.

— At the design wind load for determination of electrical clearances (i.e. three year return period) internal clearances may be reduced because there is only a low probability that there will be an overvoltage under these conditions and the occurrence of a spark over would not result in danger to persons or properties. The extent to which the clearances should be reduced has to be determined by the National Committee and reflect the required level of reliability of the line. National requirements shall be defined by NNAs.

— Under extreme wind conditions (i.e. 50 year return period) internal clearances shall withstand the highest system voltage phase-to-earth in directly-earthed neutral systems with earth fault factor of 1,3 and below. For higher earth fault factors and especially in isolated and resonant-earthed-neutral systems consideration of temporary overvoltages may be necessary.

— From still air conditions to the design wind load without ice for determination of electrical clearances (i.e. three year return period) external clearances shall meet the values, which are defined in the following subclauses. At higher wind speeds and with iced conductors clearances may be reduced. National requirements for this case shall be defined by NNAs.

5.4.2.2.4 Combined wind and ice loads

In some countries combined wind and ice loads should be considered. The methods of calculation of those load cases shall be defined in NNAs.

5.4.3 Clearances within the span and at the tower

Table 5.4.3 - Minimum clearances within the span and at the tower

	Clearance cases: within the span and at the tower				
	Within the span		At the tower		
Load Case	Phase conductor - phase conductor	Phase conductor - earth-wire	Between phases and/or circuits	Between phase conductors and earthed parts	Remarks
Maximum conductor temperature	D_{pp}	D_{el}	D_{pp}	D_{el}	Load conditions in still air
Ice load	D_{pp}	D_{el}	D_{pp}	D_{el}	Load conditions in still air
Wind load except extreme wind load	$k_1\ D_{pp}$	$k_1\ D_{el}$	$k_1\ D_{pp}$	$k_1\ D_{el}$	Because of a small probability of simultaneous occurence of an overvoltage whilst the conductor is moved by wind load, clearance may be reduced by k_1; k_1 shall be defined in NNAs.
Extreme wind load	$D_{50\ Hz\_p\_p}$	$D_{50\_Hz\_p\_e}$	$D_{50\_Hz\_p\_p}$	$D_{50\_Hz\_p\_e}$	

If the attachment of the earth wire at the tower is higher than that of the phase conductor then the earth wire shall not sag below the phase conductor.

NOTE If lines with similar conductors (same cross-sectional area, material, construction and sag) are to be considered there are approximation methods to calculate the required clearance within the span in still air to ensure that clearances are not infringed in windy conditions. Methods should be defined in NNAs or Project Specification.

5.4.4 Clearances to ground in areas remote from buildings, roads, railways and navigable waterways

Table 5.4.4 – Minimum clearances to ground in areas remote from buildings, roads, railways and navigable waterways

	Clearance to ground in unobstructed countryside		**Clearance to trees**			
	Normal ground profile	Rockface or steep slope	Under the line		Beside the line	
Load Case			Trees which cannot be climbed	Trees which can be climbed	Trees which cannot be climbed (horizontal clearance)	Trees which can be climbed (horizontal clearance)
Maximum conductor temperature	5 m + D_{el}	2 m + D_{el}; but greater than 3 m	D_{el}	1,5 m + D_{el}	D_{el}	1,5 m + D_{el}
Ice load	5 m + D_{el}	2 m + D_{el}; but greater than 3 m	D_{el}	1,5 m + D_{el}	D_{el}	1,5 m + D_{el}
Wind load	5 m + D_{el}	2 m + D_{el}; but greater than 3 m	D_{el}	1,5 m + D_{el}	D_{el}	1,5 m + D_{el}
Remarks	Basic requirement is that a vehicle or person etc. can pass under the line without danger. When that case does not apply (steep slope etc) clearance may be reduced consistent with the requirement that safety of persons shall be ensured.		Where trees or ladders are climbed under the line (for example in orchards and hop fields) then a height above the ladder or tree shall be applied so that work close to the line can be done without danger.		If the risk of causing an earth fault due to a falling tree is unacceptable, then the height of the trees shall be reduced or their horizontal distance from the line shall be limited.	
NOTE 1 In some countries it is normal practice to overspan forests to avoid lopping and in this case maximum future height of the trees should be allowed for.						
NOTE 2 These clearances are based on a 5 m high vehicle.						

5.4.5 *Clearances to buildings, traffic routes, other lines and recreational areas*

5.4.5.1 *General*

The aim of these clearances is to avoid any part of a person or any object that they can reasonably be expected to be carrying, from coming closer than the distance D_{el} from the power line. The following cases are considered:

a) Clearances to residential and other buildings, when the line is above or adjacent to the buildings or near antenna or similar structures (see Table 5.4.5.2);

b) Clearances to line crossing roads, railways and navigable waterways (see Table 5.4.5.3.1);

c) Clearances to line adjacent to roads, railways and navigable waterways (see Table 5.4.5.3.2);

d) Clearances to line crossing or parallel to other power lines or overhead telecommunication lines (see Table 5.4.5.4);

e) Clearances to recreational areas, line above and in close proximity (see Table 5.4.5.5).

NOTE Due to the increased safety requirements for crossing over buildings, recreational areas, traffic routes and other power lines, considerations should be given to the use of multiple insulator strings where there is considered to be the possibility of an insulator string mechanical failure.

5.4.5.2 Residential and other buildings

Table 5.4.5.2 – Minimum clearances to residential and other buildings

	Clearance cases: Residential and other buildings					
	Line above buildings			**Line adjacent to buildings**	**Antenna, street lamps, flag poles, advertising signs and similar structures**	
Load Case	With fire resistant roofs where the slope is greater than 15 ° to the horizontal	With fire resistant roofs where the slope is less than or equal to 15° to the horizontal	With non fire resistant roofs and fire sensitive installations such as fuel stations, etc.		Antennas and lightning protection facilities	Street lamps, flag poles, advertising signs and similar structures which can not be stood on
Maximum conductor temperature	2 m+ D_{el}, but greater than 3 m	4 m+ D_{el}, but greater than 5 m	10 m+ D_{el}	2 m+ D_{el}, but greater than 3 m (Horizontal clearance)	2 m + D_{el}	2 m + D_{el}
Ice load	2 m+ D_{el}, but greater than 3 m	4 m+ D_{el}, but greater than 5 m	10 m+ D_{el}	2 m+ D_{el}, but greater than 3 m (Horizontal clearance)	2 m + D_{el}	2 m + D_{el}
Wind load	2 m+ D_{el}, but greater than 3 m	4 m+ D_{el}, but greater than 5 m	10 m+ D_{el}	2 m+ D_{el}, but greater than 3 m (Horizontal clearance)	2 m + D_{el}	2 m + D_{el}
Extreme ice load	D_{el}	D_{el}	-	-	-	-
Remarks	It is considered that it is reasonable for a person to stand on the roof for maintenance and to use a hand tool. In the event of heavy icing it is assumed that no-one will use the roofs under this condition.	It is considered that it is reasonable for a person to stand on the roof for maintenance and to use a small ladder. In the event of heavy icing it is assumed that no-one will use the roofs under this condition.	The clearance shall be sufficient to remove the possibility that induced voltages could lead to ignition.	If this horizontal distance can not be met the vertical clearances in the case of a line above buildings shall be met.	The clearance D_{el} shall be maintained even when the structure falls towards the line conductors.	
NOTE In some countries it is not permitted in general to cross over or to be close to buildings and the clearances given in this clause do not apply to those countries. Those countries should define how close power lines can be to buildings in the NNAs.						

5.4.5.3 Traffic routes

Table 5.4.5.3.1 – Minimum clearances to line crossing roads, railways and navigable waterways

	Clearance cases: Line crossing roads, railways and navigable waterways						
Load Case	To road surface or top of rail level (if no electric traction system is used) (see NOTE 1)	To components of electric traction systems of railways, trolley bus lines or rope ways	To pulling ropes of rope ways	To an agreed gauge of a recognised navigable waterway	To fixed points of a ropeway or fixed components of an el. traction system of a railway	To towers or supporting and pulling ropes of a ropeway installation	To rope way installations in the case of undercrossing
Maximum conductor temperature	6 m + D_{el}	2 m + D_{el}	2 m + D_{el}	2 m + D_{el}	2 m + D_{el}	4 m + D_{el}	2 m + D_{el}
Ice load	6 m + D_{el}	2 m + D_{el}	2 m + D_{el}	2 m + D_{el}	2 m + D_{el}	4 m + D_{el}	2 m + D_{el}
Wind load	6 m + D_{el}	2 m + D_{el}	2 m + D_{el}	2 m + D_{el}	2 m + D_{el}	4 m + D_{el}	2 m + D_{el}
Special load case-1	-	2 m + D_{el}	2 m + D_{el}	-	-	-	-
Special load case-2	-	-	2 m + D_{el}	-	-	-	-
Special load case-3	-	-	-	-	-	-	2 m + D_{el}
Remarks	For minor roads, as defined in NNAs, clearance can be reduced by 1 m.				Horizontal clearance	Horizontal clearance	

Special load case 1 is the swinging of the over crossing conductors due to varying wind loads at a temperature defined in NNAs and simultaneously loading of the undercrossing conductor of the traction system at its minimum sag.

Special load case 2 is the swinging of the over crossing conductors due to varying wind loads at a temperature defined in NNAs and maximum tensile force in the pulling rope increased by 25 %. In evaluating horizontal clearances the following load cases shall be considered:

- swinging of the conductor due to wind towards fixed components of the ropeway installation;
- swinging ropes of the ropeway installation at maximum swing angle of 45 ° towards parts of the overhead line.

Special load case 3 is the minimum sag of the undercrossing conductor and maximum sag of the pulling rope. In addition the height of the cabin shall be considered.

NOTE 1 For clearances from the rail level, the clearance should be fixed with respect to the gauge of the train rather than the top of the rail level.

NOTE 2 If occasionally very high ice loads occur for these occasions smaller clearances may be used. In the case of crossing a railway without electric traction system clearances should be agreed by the railway authorities when conversion to an overhead traction system is planned.

Table 5.4.5.3.2 – Minimum clearances to line adjacent to roads, railways and navigable waterways

	Clearance cases: Line adjacent to roads, railways and navigable waterways			
Load case	To loading gauge or the components of an electric traction system wire installation of a railway or trolley bus line	To components of a ropeway installation	To outer edge of a carriageway (incl. hard shoulder) of a motorway, highway, country road or of a waterway	Horizontal clearance between nearest part of the overhead line and the outer edge of the nearest track of a railway
Maximum conductor temperature	0,5 m + D_{el}, but greater than 1,5 m	4 m + D_{el}	0,5 m + D_{el}, but greater than 1,5 m	4 m
Ice load	0,5 m + D_{el}, but greater than 1,5 m	4 m + D_{el}	0,5 m + D_{el}, but greater than 1,5 m	4 m
Wind load	0,5 m + D_{el}, but greater than 1,5 m	4 m + D_{el}	0,5 m + D_{el}, but greater than 1,5 m	4 m
Special load case-4	-	4 m + D_{el}	-	-
Remarks	If this horizontal clearance cannot be met, clearances for crossing of railway installations as given in Table 5.4.5.3.1 shall be met.			If conversion to electric traction system is planned 15 m.
Special load case 4: Additionally it shall be assumed that the supporting and pulling ropes of a rope way installation swing through an angle of 45 ° towards the overhead line.				

5.4.5.4 Other power lines or overhead telecommunication lines

Table 5.4.5.4 – Minimum clearances to other power lines or overhead telecommunication lines

	Crossing of lines		**Parallel lines on common structures**	**Parallel or converging lines on separate structures**
Load Case	Vertical clearance between lowest conductor of the upper circuit and live parts or earthed components of the lower line	Horizontal clearance between the vertical axis of the swung conductor and components of telecommunication lines	Clearance between conductors of lines of separate utilities	
Maximum conductor temperature	D_{pp}, but greater than 1 m [a]	-	D_{pp} [a]	D_{pp}, but greater than 1 m [a]
Ice load	D_{pp}, but greater than 1 m [a]	-	D_{pp} [a]	D_{pp}, but greater than 1 m [a]
Wind load	D_{pp}, but greater than 1 m [a]	Horizontal clearance 2 m	D_{pp} [a]	D_{pp}, but greater than 1 m [a]
Remarks	Special care shall be taken with respect to crossing of lines and parallel lines. The clearance shall be greater than 1,1 times the arcing distance a_{som} (defined as the straight line distance between live and earthed parts) of the insulator string.			
		If this horizontal clearance can not be met, the vertical clearances between lowest conductor of the upper circuit and live parts or earthed components of the lower line shall be met.	If circuits of separate utilities are placed on common structures, the possibility of influencing each other shall be minimised; i.e. consideration should be given to the use of rotating crossarms, consequences of broken insulators, induction and maintenance.	

[a] D_{pp} is the greater of the values of D_{pp} for the two lines.

5.4.5.5 Recreational areas (playgrounds, sports areas etc.)

Table 5.4.5.5 – Minimum clearances to recreational areas

	Line above				**Line in close proximity**
Load Cases	To general sports areas	To highest level of swimming pools	To agreed gauge of sailing facilities	To permanently installed sports facilities like starting and winning post installations, camping installations as well as structures which can be erected or climbed on	Horizontal clearance to all recreational installations
Maximum conductor temperature	7 m + D_{el}	8 m + D_{el}	1 m + D_{el}	3 m + D_{el}	3 m + D_{el}
Ice load	7 m + D_{el}	8 m + D_{el}	1 m + D_{el}	3 m + D_{el}	3 m + D_{el}
Wind load	7 m + D_{el}	8 m + D_{el}	1 m + D_{el}	3 m + D_{el}	3 m + D_{el}
Remarks	In the case of a sport with throwing of implements or shooting, it shall be ensured that an approach to the conductor less than 2 m + D_{el} is avoided.	In case of a diving board, it shall be ensured that an approach of anyone closer than D_{el} is avoided.			If this horizontal clearance is not met, then the vertical clearances for the line above condition shall be met.

NOTE In some countries it is not permitted in general to cross over or run close to recreational areas and the clearances given in this clause do not apply to these countries. Those countries should define how close power lines can be to recreational areas in the NNAs.

5.5 Corona effect

5.5.1 Radio noise

5.5.1.1 General

Radio noise from high voltage overhead power lines can be generated over a wide band of frequencies by:

- corona discharges in the air at the surfaces of conductors and fittings;
- discharges and sparking at highly electrically stressed areas of insulators;
- sparking at loose or imperfect contacts.

There are two basic methods to predict the radio noise of a high-voltage line: comparative and analytical.

NOTE These methods are described and compared in CISPR 18-3 and CIGRÉ Working Group 36.01 (1974) Document "Interferences produced by corona effect of electrical systems".

5.5.1.2 Design influences

The most important design influence on the corona-generated radio noise levels produced by any high-voltage line is the electric field very close to the conductors. This field is influenced by voltage, number of conductors per phase bundle, size of conductors, phase spacing, and to a lesser extent, line configuration, line phasing, line height, and line proximity to other lines or wires. Radio noise levels are also influenced by the local earth conductivity and the relative smoothness of conductor and hardware surfaces.

Generally, corona generated radio-noise levels become a significant design concern only for lines operating at voltages of 230 kV or above. For these high voltages, noise-level prediction methods assume that line hardware is designed or shielded so that only the corona on conductors will be responsible for observed radio noise levels, and that conductors are installed taking care not to damage their surface. In the first few months of energised operation, conductor surfaces are not yet weathered, and radio noise levels can be a few decibels above ultimate expectations.

A practical design of overhead lines and associated equipment in order to keep the various types of radio noise within acceptable levels is described in CISPR 18-3.

5.5.1.3 Noise limits

The degree of annoyance caused by radio noise is determined by the so-called "signal-to-noise ratio" at the receiving installation. When establishing limits for the emission of radio noise, the radio and television signal strengths to be protected have to be determined.

Maximum permissible levels of radio noise may be given by national or local authorities and incorporated in NNAs or the Project Specification.

Methods for derivation of limits of radio noise from overhead power lines and high-voltage equipment in order to safeguard radio and television reception are given in CISPR 18-2.

5.5.2 Audible noise

5.5.2.1 General

Corona on high-voltage power lines can, in some circumstances, produce audible noise. Such noise is more likely to occur in foul weather and fog; in fair weather it arises mainly where lines are subject to special kinds of pollution.

The principal source of foul weather acoustic noise is water drops. Whether hanging from a wet line, arriving at the line as rain drops, or streaming from the line, water can give rise to various types of discharge. Rime on conductors may also give rise to noise.

Both comparative and analytical methods exist which predict A-weighted levels of audible noise for proposed high-voltage lines.

The methods currently available are described and compared in an IEEE Subcommittee report (1982) "A comparison of methods for calculating audible noise of high voltage transmission lines" and in CIGRÉ Working Group 36.01 "Interferences produced by corona effect of electrical systems" (1974).

5.5.2.2 Design Influences

The most important design influence on the audible noise levels produced by a high-voltage line is the electric field very close to the conductors (surface electric gradient). This field is influenced by voltage, number of conductors per phase bundle, size of conductors, phase spacing, and to a lesser extent, line configuration, line phasing, line height, and line proximity to other lines or wires. Audible noise levels are further influenced by the relative smoothness of conductor and hardware surfaces and contamination due to hydrophobic materials.

In general, audible noise levels become a significant design concern only for lines operating at voltages of 400 kV or above. For these high voltages, noise-level prediction methods assume that line hardware is designed or shielded so that only the corona on conductors will be responsible for observed audible noise levels in wet weather, and that conductors are installed taking care not to damage their surfaces. As with radio noise, audible noise levels may be a little above ultimate expectations during an initial weathering period.

5.5.2.3 Noise limit

Maximum permissible levels of audible noise may be given by national or local authorities and specified in NNAs or the Project Specification, preferably as a weighted noise level in dB above the background noise level at a specified distance from the line.

5.5.3 Corona loss

The corona loss is the power lost due to corona emission. On overhead power lines, corona loss is expressed in watts per metre (W/m) or kilowatts per kilometre (kW/km).

The power loss due to corona is typically less than a few kilowatts/kilometre in fair weather but, it can amount to tens of kilowatts/kilometre during heavy rain and up to one hundred kilowatts/kilometre during frost.

The magnitude of fair-weather corona loss is insignificant in comparison with foul-weather loss (maximum corona loss). However, fair weather losses occur for a large percentage of time and affect the value of the total energy consumed by the line (yearly average corona loss). In some countries corona loss can be higher in winter.

Maximum permissible values of corona loss may be defined in the NNAs or Project Specification in terms of fair weather and foul weather losses in kW/km/year.

5.6 Electric and magnetic fields

5.6.1 Electric and magnetic fields under a line

The design of transmission lines can be influenced to a great extent by the necessity to limit electric and magnetic fields produced by energised conductors.

Basic parameters and methods for the evaluation of power frequency electric and magnetic fields are the following:

Electric fields can be determined by using different analytical and numerical methods, or reduced-scale models. The choice of the most suitable method depends on the complexity of the problem to be solved and on the required degree of accuracy.

The method of equivalent charges is applicable when the problem is to calculate the electric field near the ground under overhead lines.

The validity of the above two-dimensional assumptions shall be duly evaluated in the presence of three-dimensional effects (i.e. sag of conductors, proximity to towers, irregular ground levels, changes in line direction). If necessary, correction factors may be applied or fully dimensioned calculations made.

Magnetic field calculation may call for different methods depending on the problem to be solved, on the nature of the materials surrounding the conductors and on the required degree of accuracy. However, for many purposes, it is adequate to apply the fundamental Ampere's law, which gives the intensity of magnetic field produced by each current carrying conductor.

Limit values for electric and magnetic fields are not provided in this standard. For such limits, reference shall be made where relevant to appropriate Standards and Safety Codes which shall be defined in the NNAs.

5.6.2 Electric and magnetic field induction

Electro-magnetic fields near an overhead line may induce currents in and voltages on adjacent conductive objects.

Induction effects shall be considered in the case of long metal structures (e.g. communication installations, fences, lines or pipes) or bulky objects (e.g. conductive roofs, tanks or large vehicles) in proximity to power lines.

Electricity companies shall be able to take any measures to prevent/remove potentially dangerous or simply annoying induction effects. To this purpose, suitable procedures shall be agreed by the parties concerned.

Prevention measures range from optimisation of the sources by proper arrangement of the circuits to adequate shielding (screens are acknowledged as very efficient against electric fields, while it is generally recognised that there is no adequate and practical way to shield against magnetic fields on a large scale).

Most of the effects relate to the induction of voltages on metallic structures or objects which are not in good electrical connection to the ground. In these cases each conductive part shall be connected to earth.

Long metal structures which are electrically connected to the ground at one or a few places and which run parallel to electric power lines shall be connected to ground at appropriate intervals and/or broken with insulating elements to reduce loop sizes.

5.6.3 Interference with telecommunication circuits

Telecommunication circuits can suffer electrical interference from power lines.

For interference calculations and measures to be taken to eliminate the effects or reduce them to acceptable levels, reference shall be made to relevant International and National Standards and/or to qualified Codes of Practice (i.e. ITU Directives (CCITT) Vol. VI "Danger and Disturbance", 1989) and/or to particular agreements between the parties concerned.

Attention shall also be paid to the possibility of induced voltages that can represent danger to persons.

NOTE European Standards in this field are being prepared by CENELEC CLC/TC210 WG03: EN 50351 and EN 50352.

6 Earthing systems

6.1 Purpose

This clause gives the criteria for the design, installation and testing of the earthing system such that it operates under all conditions and keeps the step and touch voltages within acceptable levels.

Depending on the design of the line, type of supports and local conditions, earthing systems can become necessary.

6.2 Dimensioning of earthing systems at power frequency

6.2.1 General

The design of earthing systems shall meet five requirements:

a) To ensure mechanical strength and corrosion resistance.
b) To withstand, from a thermal point of view, the highest fault current as determined by calculation.
c) To avoid damage to properties and equipment.
d) To ensure personal safety with regard to voltages on earthing systems which appear during the earth fault.
e) To ensure a certain reliability of the line.

Parameters relevant to earthing system dimensioning are thus:

- Value of fault current;
- Fault duration;

  NOTE The above parameters are mainly dependent on the method of earthing the neutral of the system.
- Soil characteristics.

When an overhead line is constructed with two or more different voltage levels, the five requirements for the earthing system shall be met for each voltage level. Simultaneous faults in different voltage circuits need not be considered.

Supports of conducting material are in principle earthed by their footings, but additional measures for earthing may be required.

Supports of non-conducting material need not be earthed.

In the case of power lines containing earth wires along the whole length, earthing impedance shall be determined including the effect of earth wires.

6.2.2 Dimensioning with respect to corrosion and mechanical strength

6.2.2.1 Earth electrodes

The electrodes, being directly in contact with the soil, shall be of materials capable of withstanding corrosion (chemical or biological attack, oxidation, formation of an electrolytic couple, electrolysis, etc.). They shall resist the mechanical influences during their installation as well as those occurring during normal service.

Mechanical strength and corrosion considerations dictate the minimum dimensions for earth electrodes given in G.2. If a different material, for example stainless steel, is used, this material and its dimensions shall meet the requirements a) and b) in 6.2.1.

NOTE It is acceptable to use steel reinforcing bars embedded in concrete foundations and steel piles as a part of the earthing system.

6.2.2.2 Earthing and bonding conductors

For mechanical and electrical reasons, the minimum cross-sections shall be:

- copper 16 mm²;
- aluminium 35 mm²;
- steel 50 mm²;

NOTE Composite conductors can also be used for earthing provided that their resistance is equivalent to the examples given. For aluminium conductors corrosion affects should be considered. Earthing and bonding conductors made of steel require protection against corrosion.

6.2.3 Dimensioning with respect to thermal strength

6.2.3.1 General

Because fault current levels are governed by the electrical system rather than the overhead line the values should be provided by the network utility.

NOTE 1 In some cases steady-state zero-sequence currents should be taken into account for the dimensioning of the relevant earthing system.

NOTE 2 For design purposes, the currents used to calculate the conductor size should take into account the possibility of future growth.

The fault current is often subdivided in the earth electrode system; it is, therefore, possible to dimension each electrode for only a fraction of the fault current.

The final temperatures involved in the design and to which reference is made in the following subclause shall be chosen in order to avoid reduction of the material strength and to avoid damage to the surrounding materials, for example concrete or insulating materials.

No permissible temperature rise of the soil surrounding the earth electrodes is given in this standard because experience shows that soil temperature rise is usually not significant.

6.2.3.2 Current rating calculation

The calculation of the cross-section of the earthing conductors or earth electrodes depending on the value and the duration of the fault current is given in G.3. There is a discrimination between fault duration lower than 5 s (adiabatic temperature rise) and greater than 5 s. The final temperature shall be chosen with regard to the material and the surroundings.

Nevertheless, the minimum cross-sections in 6.2.2 shall be observed.

6.2.4 Dimensioning with regard to human safety

6.2.4.1 Permissible values

The current passing through the human body is the cause of danger. IEC 60479-1 gives guidance on the effects of current flowing through the human body due to its magnitude and duration. In practice, it is more convenient to refer to touch voltages. Touch voltage limits are given in Figure 6.2. The curve, U_{D1}, represents the value of voltage that can appear across the human body, bare hand to bare feet. No additional resistances have been considered in that curve.

Nevertheless, it is permitted to use the calculations given in G.4, to take account of additional resistances such as footwear or protective high resistivity materials.

Every earth fault will be disconnected automatically or by hand. Thus indefinitely applied touch voltages do not appear as a consequence of earth faults.

For step voltages this standard does not define permissible values.

NOTE Permissible values of step voltages are somewhat greater than the permissible touch voltages; therefore, if an earthing system satisfies the touch voltage requirements, then it can be assumed that in most cases no dangerous step voltages will occur.

For the relevant fault duration the correct operation of protection and interrupting devices is taken into account.

Methods of calculation and values of touch voltage shall be specified in the NNAs or the Project Specification.

6.2.4.2 Measures for the observance of permissible touch voltages

Application of the requirements a), b) and c) in 6.2.1 will give the basic design of the earthing system. This design shall be checked with respect to the danger of too high touch voltages and can then be considered as a type design for similar situations.

The block diagram of Figure 6.1 shows a general approach to the design of an earthing system with regard to permissible touch voltage. Numbers between parentheses are explained after the Figure.

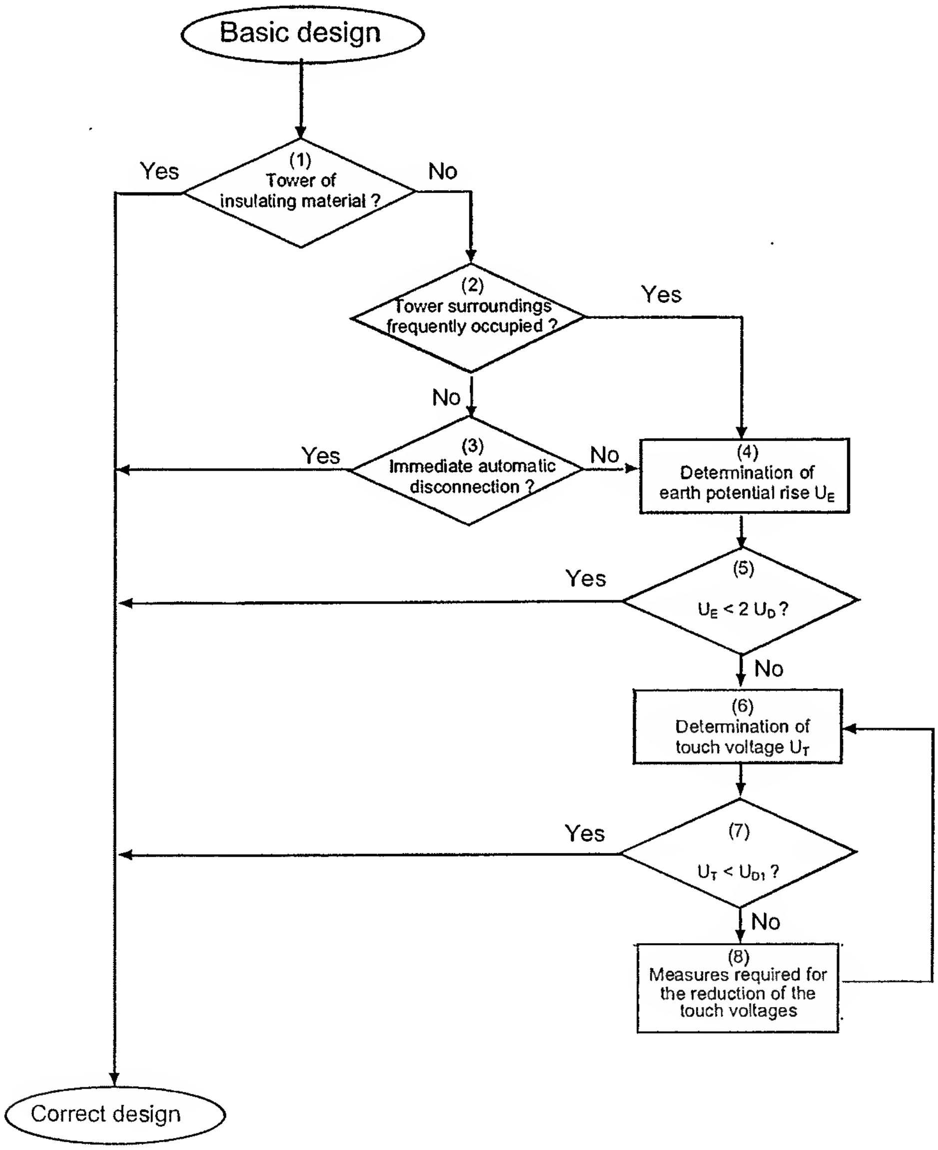


Figure 6.1 - Design of earthing systems with regard to permissible touch voltage

All the following explanatory remarks are related to Figure 6.1.

1) For wood or other non conductive poles or towers without any conducting parts to earth, earth faults are not possible in practice and there are no requirements for earthing.

2) Towers at locations which are freely accessible to people and where people can be expected to be either for a relatively long time (some hours per day) during some weeks, or for a short time but very frequently (many times a day) for example close to residential areas or play grounds, are included and shall be reviewed in more detail. Locations which are only occasionally occupied such as forests, open country sides etc. are not included.

3) Towers at locations that are not freely accessible or where access by people will be rare, the touch voltages need not be considered in those cases where the line is provided with automatic disconnection for protection.

   If it can be assumed that access by people will be rare then the probability of this access and the incidence of a simultaneous automatically cleared fault can be considered negligible and thus the earthing design can be considered satisfactory.

4) See H.4.3.

5) See Figure 6.2. If earth potential rise is lower than $2U_D$ related to appropriate circumstances 1,2,3 or 4 then the design can be considered acceptable. The touch voltage under most of these circumstances is only a fraction of earth potential rise, which is explained in detail in G.4.1.

6) See G.4.

7) See Figure 6.2, curve U_{D1}, which is the same as U_{TP}, permissible touch voltage.

8) If the condition given in remark (7) is not satisfied, then measures to reduce the touch voltage shall be taken, until requirements are met. These measures may be specified in the NNAs.

NOTE These measures can be for example: buried potential grading rings, insulation of the tower, increase of the resistance of the upper soil layer, etc.

Transferred potentials if they occur shall always be checked by a separate calculation.

6.2.4.3 Touch voltage limits at different locations

Figure 6.2 shows touch voltage limits (voltage differences) which can appear across the human body at different typical locations. The curves U_{D2}, U_{D3} and U_{D4} illustrate the effects of progressively increased additional resistances.

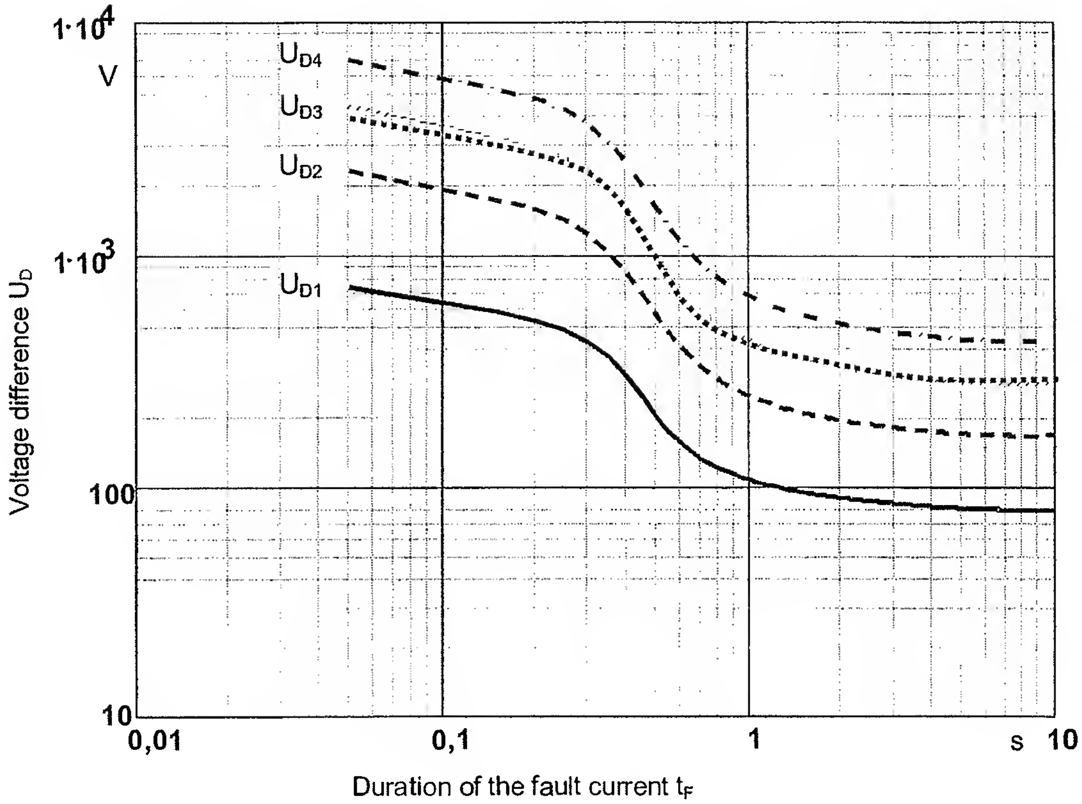


Figure 6.2 - Examples of touch voltage limits (voltage difference U_D) as a function of the duration of the fault current t_F

The voltage difference, U_D, acting as a source voltage in the touching circuit with a value that guarantees the safety of a person when there are additional resistances R_a, see G.4.2. The curves in Figure 6.2 are:

Curve U_{D1} : R_a = 0 Ω (example 1).
Curve U_{D2} : R_a = 1 750 Ω , R_{a1} = 1 000 Ω , ρ_E = 500 Ω.m (example 2).
Curve U_{D3} : R_a = 4 000 Ω , R_{a1} = 1 000 Ω , ρ_E = 2 000 Ω.m (example 3).
Curve U_{D4} : R_a = 7 000 Ω , R_{a1} = 1 000 Ω. , ρ_E = 4 000 Ω.m (example 4).

Description of typical locations corresponding to the above mentioned examples 1 to 4 and curves U_{D1} to U_{D4} in Figure 6.2.

— Example 1. Curve U_{D1}.

Locations such as play grounds, swimming pools, camping areas, recreational areas and similar locations where people may gather with bare feet. No additional resistance other than the body resistance is considered.

— Example 2. Curve U_{D2}.

Locations where it can be reasonably assumed that people are wearing shoes such as pavements of public roads, parking places etc. The additional resistance of 1 750 Ω is considered.

— Example 3. Curve U_{D3}.

Locations where it can be reasonably assumed that people are wearing shoes and the soil resistivity is high e.g. 2 000 Ω·m. The additional resistance to be taken into account is 4 000 Ω.

— Example 4. Curve U_{D4}.

Locations where it can be reasonably assumed that people are wearing shoes and the soil resistivity is very high e.g. 4 000 Ω·m. The additional resistance to be taken into account is 7 000 Ω.

6.2.4.4 Measures in systems with isolated neutral or resonant earthing

In systems with isolated neutral or with resonant earthing, where touch voltages are higher than the permissible value, one of the following measures may be taken in order to make sure that a long lasting earth fault at the tower is unlikely to occur or the duration of the earth fault is limited to a short duration:
— using long rod insulators or solid core insulators;
— using insulators of which the insulation performance may be seen by visual inspection (for instance cap and pin insulators of glass);
— using an earth fault detection tool and disconnecting the line, if an earth fault occurs.

6.3 Construction of earthing systems

6.3.1 Installation of earth electrodes

An earthing system is generally composed of one or more horizontal, vertical or inclined electrodes, buried or driven into the soil by force. It can also consist of the direct embedded tower itself.

The use of chemicals to reduce soil resistivity is not recommended, because it increases corrosion, needs periodical maintenance and is not long lasting. However in special circumstances the use of chemicals may be justified.

Horizontal earth electrodes should usually be buried at a depth of 0,5 m to 1 m below ground level. This gives sufficient mechanical protection. It is recommended that the earth electrode is situated below the frost line.

In the case of vertically driven rods, the top of each rod will usually be situated below ground level. Vertical or inclined driven rods are particularly advantageous when the soil resistivity decreases with increasing depth.

General installation details can be found in H.3.

6.3.2 Transferred potentials

The transfer of potential may occur due to metallic pipes and fences, low voltage cables etc. and general guidelines are difficult to provide especially because circumstances vary from one case to another. Guidelines on individual cases should be determined by the utility. Proposals from IEC TC 64 also give guidance.

Rules for telecommunication systems on or in the vicinity of high voltage earthing systems are outside the scope of this standard. When considering transferred potentials due to telecommunication systems, existing international documents (i.e. ITU directives) shall be taken into account.

6.4 Earthing measures against lightning effects

The footing resistance values have an influence on the backflashover rate of the line and therefore affect the reliability of the line. However it is not within the scope of this standard to specify the reliability, because that is matter of optimisation in individual projects. Maximum or reference resistance values shall be specified in the NNAs or Project Specification.

6.5 Measurements for and on earthing systems

General advice concerning measurements is given in H.4.

Touch voltages shall be measured according to G.5.

6.6 Site inspection and documentation of earthing systems

A site plan of an earthing system be provided which shows the material and the position of the earth electrodes, their branching points and the depth of burial.

If specific measures are needed to achieve permissible touch voltages, they shall be included in the site plan and shall be described in the Project Specification.

7 Supports

7.1 Initial design considerations

In order to properly and efficiently design the structures, it is recommended to provide the information specified in annex L.

Unless otherwise specified, durability shall comply with the specific requirements of the parent structural Eurocodes: ENV 1992-1-1, ENV 1993-1-1 and ENV 1995-1-1.

Some numerical values identified by $\boxed{}$ "boxed values" in the following subclauses may be amended in the NNAs or the project specification.

If a defined life-time is required, a reference time-period specifying environmental conditions, environmental requirements, maintenance management strategy, performance criteria, ..., shall be specified in the NNAs and/or in a project specification prior to an order.

7.2 Materials

7.2.1 Steel materials, bolts, nuts and washers, welding consumables

Materials used in the fabrication of transmission line supports shall comply with the requirements of ENV 1993-1-1: chapter 3, annex B and annex D in preparation. European standards EN 10149 and ENV 1090-1: chapter 5 shall also be considered. In general, materials for steel sections should comply with EN 10025.

In the absence of other applicable European Standards relating to other steel grades, steel products, bolts, nuts, washers, welding consumables, etc., the National Application Documents (NAD), which link European Standards with National Standards, are applicable.

7.2.2 Cold formed steel

These materials shall comply with the requirements of ENV 1993-1-3.

7.2.3 Requirements for steel grades subject to galvanising

Except where otherwise specified, when steels are to be galvanised, in order to avoid dull dark grey and excessively thick coating which may result in an increased risk of coating damage, it is recommended that the maximum silicon (Si) and phosphorus (P) contents meet the requirements of EN ISO 1461 - subclause C.1.4.

7.2.4 Holding-down bolts

Unless stated to the contrary in a project specification, the material toughness (steel grade) of holding-down bolts shall be calculated in accordance with annex C of ENV 1993-1-1, but the test temperature shall not be greater than 0 °C. Anchor bolt nuts shall be compatible with the anchor bolt strength.

7.2.5 Concrete and reinforcing steel

Concrete and reinforcing steel shall be specified in conformity with the requirements of ENV 1992-1-1.

7.2.6 Timber

Timber poles shall be specified in conformity with the requirements of ENV 1995-1-1, EN 12465, EN 12479, EN 12509, EN 12510 and EN 12511.

7.2.7 Guy materials

The guy material properties, including the characteristic strength, shall be taken from the relevant standards. The characteristic strength of the guy fittings and insulators shall be at least that of the guy itself.

7.2.8 Other materials

For all other materials, the material characteristics should be in accordance with the performance requirements of the finished product and shall also meet the functional requirements regarding both strength and serviceability (deformation, durability and aesthetics).

Account shall be also taken of the project specification and NNAs.

7.3 Lattice steel towers

7.3.1 General

The requirements of the ENV 1993-1-1 should be complied with, except where otherwise specified below.

In the following subclauses reference is made to the corresponding chapters of ENV 1993-1-1 in brackets.

This subclause refers generally to angle members. For the design of other types of members, reference should be made to ENV 1993-1-1, except for those included in 7.3.5.4 - Resistance of lattice members and 7.3.6 - Connections.

7.3.2 Basis of design (Chapter 2)

1) The rules given in clause 3 "Basis Of Design" are applicable.

2) Unless otherwise specified, it is not necessary to consider seismic effects, fatigue or fire resistance. Members on which it is possible for a man to stand shall be designed to resist a load as specified in 4.2.6.2.

7.3.3 Materials (Chapter 3)

1) Materials shall comply with 7.2

7.3.4 Serviceability limit states (Chapter 4) (refer also to NNAs)

1) It is normally unnecessary to consider deflections or vibration of lattice towers, unless specified in a project specification.

2) The serviceability limits are related to the tower geometry, and shall be defined in compliance with the required electrical clearances (to ground and to structure) as given in clause 5 "Electrical requirements".

7.3.5 Ultimate limit states (Chapter 5)

7.3.5.1 Basis (Chapter 5.1)

7.3.5.1.1 General (Chapter 5.1.1)

1) Steel structures and components shall be so proportioned that the basic design requirements for the ultimate limit state given in clause 3 "Basis of design" are satisfied.

2) The partial safety factors γ_M shall be taken as follows:

— resistance of cross sections	$\gamma_{M\,1}$	=	1,10
— resistance of members to buckling	$\gamma_{M\,1}$	=	1,10
— resistance of net section at bolts holes	$\gamma_{M\,2}$	=	1,25
— resistance of connections: see 7.3.6			

7.3.5.2 Calculation of internal forces and moments (Chapter 5.2)

7.3.5.2.1 Global analysis (Chapter 5.2.1)

a) Method of analysis (Chapter 5.2.1.1)

1) The internal forces and moments in a statically indeterminate structure shall be determined using elastic global analysis.
Lattice steel towers are normally considered as pin jointed truss structures.
If the continuity of a member is considered, the consequent secondary bending stresses may generally be neglected.
Approximate calculation of member loads by considering tower panels as two-dimensional trusses is acceptable providing the equilibrium conditions are satisfied.
It shall be verified that bracing systems have adequate stiffness to prevent local instability of any parts.

b) Effects of deformations (Chapter 5.2.1.2)

1) The internal forces and moments may generally be determined using either:
— first order theory, using the initial geometry of the structure, or
— second order theory, taking into account the influence of the deformation of the structure.

2) Normally first order theory is used for the global analysis of self-supporting lattice towers.

c) Elastic global analysis (Chapter 5.2.1.3)

1) Elastic global analysis shall be based on the assumption that the stress-strain behaviour of the material is linear, whatever the stress level.

2) The assumption may be maintained for both first-order and second-order elastic analysis.

3) Three types of members are considered: main legs and chords, bracings and secondary members (often referred to as redundant members).

The secondary members are considered not to be loaded directly by external actions, and assure the local stability of members carrying loads.

In the global analysis network the redundant members can normally be neglected.

4) Bending moments due to normal eccentricities are treated in the selection of buckling cases.

5) Bending moments caused by wind loads on individual member are generally negligible, but they may need to be considered in the design of slender bracings or horizontal edge members see J.6.3.1 (4) and J.7.1 (4).

7.3.5.3 Classification of cross sections (Chapter 5.3)

Sections used in lattice towers shall be considered to be class 3 or 4. The effective cross section shall be determined, to take into account the local buckling, according to annex J.

7.3.5.4 Resistance of lattice members (Chapter 5.4 and Chapter 5.5)

The resistance of cross sections against tension, compression and bending, and the buckling resistance of members shall be determined in accordance with annex J.

7.3.6 Connections (Chapter 6)

7.3.6.1 Basis (Chapter 6.1)

7.3.6.1.1 General (Chapter 6.1.1)

1) All connections shall be capable of resisting their applied loads, so that the basic design requirements given in clause 3 are satisfied.

2) The partial safety factors γ_M shall be taken as follows:

— resistance of bolted connections	$\gamma_{M\,b}$	=	1,25
— resistance of riveted connections	$\gamma_{M\,r}$	=	1,25
— resistance of welded connections	$\gamma_{M\,w}$	=	1,25

7.3.6.1.2 Resistance of connections (Chapter 6.1.3)

1) The resistance of a connection shall be determined on the basis of the resistances of the individual fasteners or welds.

7.3.6.1.3 Classification of connections (Chapter 6.4)

Connections are generally considered as nominally pinned.

7.3.6.2 Connection with bolts (Chapter 6.5)

7.3.6.2.1 Positioning of holes (Chapter 6.5.1)

1) The positioning of holes for bolts shall be such as to prevent corrosion and local buckling and to facilitate the installation of the bolts.

2) For the positioning of holes in a connection, reference shall be made to ENV 1993-1-1.

7.3.6.2.2 Categories of bolted connections (Chapter 6.5.3)

1) The design of a bolted connection shall conform to the category to which it is classified.

2) The categories of bolted connections are defined in ENV 1993-1-1.

7.3.6.2.3 Design resistance of bolts (Chapter 6.5.5)

1) The design resistance of bolts in shear, bearing and tension are given in J.11.

7.3.6.3 Welded connections (Chapter 6.6)

7.3.6.3.1 General requirements for welding (Chapter 3.3.5 and Chapter 7.6)

1) Connections made by welding shall generally conform with the relevant requirements for materials and execution specified in ENV 1993-1-1.

2) Welding operations shall be in accordance with ENV 1090-1.

7.3.6.3.2 Design resistance of welds (Chapter 6.6.5 and 6.6.6)

1) The design resistance of fillet welds shall be determined in accordance with ENV 1993-1-1.
2) The design resistance of full penetration butt welds shall be determined in accordance with ENV 1993-1-1.
3) The design resistance of a partial penetration butt weld shall be determined in accordance with ENV 1993-1-1.

7.3.6.4 Embedding of steel members into concrete by mean of anchoring elements

The total tensile or compression load of steel members anchored in concrete is transferred to the concrete by two methods:

— Steel angle stubs with anchoring elements such as angle cleats or studs. These shall be checked for shear due to the compression stresses between the element and the concrete. No bending moment in cleats or studs should be considered (reference is made to 5.4.8 of ENV 1992-1-1).

— Base plate and holding-down bolts. The holding-down bolts shall be checked for shear, axial load as well as possible bending moments due to lateral displacement of the bolts. For design purpose reference shall be made to annex K.

7.3.7 Fabrication and erection (Chapter 7)

Reference is made to ENV 1993-1-1 and to ENV 1090-1.

7.3.8 Design assisted by testing (Chapter 8)

Experimental verification by a full-scale test may be required to validate the calculated resistance of either a complete tower or a part of it. The full-scale test shall be carried out to determine the load resistance $F_{test,R}$. Only one test shall be carried out on a specimen nominally identical with the series manufacture. The minimum test load shall be determined from:

$$F_{test,R} > \boxed{1{,}05} \cdot F_{R,d}$$

where $F_{R,d}$ = design load for the ultimate limit state.

Alternatively, when the test has been continued up to failure, the results may be used for analysis by recalculating the design strength with the actual characteristics of the specific element that led to damage.

7.4 Steel poles

7.4.1 General

The requirements of ENV 1993-1-1 shall be complied with, except where otherwise specified below.

In the following subclauses reference is made to the corresponding chapters of ENV 1993-1-1 in brackets

7.4.2 Basis of design (Chapter 2)

1) The rules given in clause 3 “Basis of design” are applicable.

2) Unless otherwise specified, it is not necessary to consider seismic effects, fatigue or fire resistance.

3) If a dynamic analysis is required, it shall be done taking into account the different factors influencing the behaviour of the pole such as conductors, dampers and foundations. Dynamic effects, where appropriate, may be taken account of by applying dynamic factors to the loading, and adopting a quasi-static design approach.

7.4.3 Materials (Chapter 3)

1) Materials shall comply with 7.2

2) The grades of structural steel subjected to loads shall reflect the manufacturing process and the minimum service temperature, but in general a Charpy V-notch energy of 40 J at – 20 °C for steel thicknesses greater than 6 mm is recommended for steel poles or tubular welded structures.

7.4.4 Serviceability limit states (Chapter 4) (refer also to NNAs)

1) Appropriate limiting values of deformations and deflections shall be agreed between the client and the designer.

2) The serviceability limits for are related to the pole geometry and shall be defined in compliance with the required electrical clearances (to ground and to structure) as given in clause 5 “Electrical Requirements”.

7.4.5 Ultimate limit states (Chapter 5)

7.4.5.1 Basis (Chapter 5.1)

1) Steel poles and components shall be so proportioned that the basic design requirements for ultimate design state given in clause 3 “Basis of design” are satisfied.

2) The partial safety factors γ_M shall be taken as follows:

— resistance of cross sections	$\gamma_{M\,1}$	=	1,10
— resistance of net section at bolts holes	$\gamma_{M\,2}$	=	1,25
— resistance of connections: see 7.4.6			

3) It is recommended that the deflection under a second order analysis at the ultimate limit state does not exceed 8 % of the height of the pole above ground level.

7.4.5.2 Calculation of internal forces and moments (Chapter 5.2)

1) The internal forces and moments in any transverse section of the structure shall be determined using elastic global analysis.

2) The second order theory, taking into account the influence of the deformation of the structure, shall be used for the global analysis of steel poles.

3) Global elastic analysis shall be based on the assumption that the stress-strain behaviour of the material is linear, whatever the stress level.

4) The design assumptions for the connections shall satisfy the requirements specified in 7.4.6.

7.4.5.3 Classification of cross sections (Chapter 5.3)

For steel poles, only class 3 and class 4 cross sections, according to the definition given in 5.3 of ENV 1993-1-1, shall be considered and the analysis limited to elastic behaviour.

7.4.5.4 Resistance of cross sections (Chapter 5.4)

1) The resistance of cross sections of steel poles shall be determined in accordance with the requirements of annex K.
   The effective cross section shall be determined, to take into account the local buckling, according to annex K.
2) Vertical reinforcing stiffeners around openings shall be designed to resist buckling in order to satisfy the general requirements of ENV 1993-1-1 including the connections (welds, bolts, etc.).

7.4.6 Connections (Chapter 6)

7.4.6.1 Basis (Chapter 6.1)

1) All connections shall have a design resistance such that the structure remains effective, and that the basic design requirements given in clause 3 "Basis of design" are satisfied.
2) The partial safety factors γ_M shall be taken as follows:

— resistance of bolted connections			
bolts in shear or bearing	$\gamma_{M\ bs}$	=	1,25
bolts in tension	$\gamma_{M\ bt}$	=	1,25
— resistance of welded connections	$\gamma_{M\ w}$	=	1,25

7.4.6.2 Bolts (other than holding-down bolts)

1) The design resistance of bolts in shear, bearing or tension is given in 6.5.5 of ENV 1993-1-1.
2) The design resistance of preloaded high strength bolts is given in 6.5.8 of ENV 1993-1-1.

7.4.6.3 Slip joint connections

These connections need not be justified by calculation if the following requirements are observed:

1) When modelling the pole for global elastic analysis, only the nominal inside male section in the splice area shall be considered for resistance.
2) The connections are defined, on drawings, with a nominal lap at least equal to 1,5 times the maximum average diameter across angles of the female section.
3) The assembly is carried out on site. To take into account variations in thickness due to the galvanising and dimensional variations of the polygonal section, the minimum effective length of jointing shall be greater than1,35 times the maximum average diameter across the angles of the female section.

   However, the sum of the slip tolerances at each joint shall comply with the pole length tolerance defined in the NNAs or in the project specification.
4) The jointing force shall exceed the maximum factored design vertical compressive force at joint level.

5) When necessary anchoring devices on either sides of the slip joint shall be provided on the pole in order to ensure on the site a proper splicing using hydraulic jacks or pulling devices according to the supplier recommendations.

7.4.6.4 Flanged bolted connection

1) Preloaded high strength bolts of property class 8.8, 10.9 or similar shall be used.

2) It is recommended that the centre distance between bolts should be less than 5 times the diameter of the bolts.

3) The stress in the bolts shall be calculated taking due consideration of the eccentricity of the loading transmitted through the connection as specified in 6.5.9 of ENV 1993-1-1.

4) The design resistance of bolts in shear, bearing and tension are given in annex J.

7.4.6.5 Welded connections

1) The design resistances of fillet welds and butt welds are given in 6.6.5 and 6.6.6 of ENV 1993-1-1.

2) Welding operations shall be in accordance with ENV 1090-1.

3) Connections made by welding shall generally conform to the relevant requirements for materials and execution specified in ENV 1993-1-1 Chapters 3, 7 and 9.

4) Complete penetration longitudinal welds shall be used in the splice area of the female section. In other areas, partial penetration longitudinal welds with a minimum of 60 % may be used if they comply with the strength requirements.

7.4.6.6 Direct embedding into the concrete

1) Pole-to-foundation connection should be made preferably by direct embedding of the bottom part of the steel pole into the concrete

2) The length of the section of the pole embedded into the concrete should be determined using a linear loads distribution in conformity with requirements of ENV 1992-1-1 and ENV 1993-1-1.

3) Due consideration should be given to the buckling of the steel section if the part of pole embedded is not filled with concrete.

7.4.6.7 Base plate and holding-down bolts

1) The base plate and the holding-down bolts shall be adequate to take the applied loads developed at the joint between the structure and the foundation or supporting structure (reference is made to 6.5.9 of ENV 1993-1-1).

2) The design of the anchorage length of bolts into concrete is given in annex K.

3) The holding-down bolts shall be checked for shear and axial load. Due care shall be taken for possible bending moment due to lateral displacement of the bolts while there is no grouting.

4) An appropriate grouting material, correctly applied, shall be inserted between the base plate and the top of the foundation concrete to ensure the transfer of the shear load. In its absence, the method of load transfer by the holding-down bolts shall be verified. Satisfactory means of drainage and/or ventilation shall be provided to prevent accumulation of water inside poles.

7.4.7 Fabrication and erection (Chapter 7)

Reference is made to ENV 1993-1-1 and to ENV 1090-1.

7.4.8 Design assisted by testing (Chapter 8)

Experimental verification by a full-scale test may be required to validate the calculated resistance of either a complete steel pole or a part of the structure. The full-scale test shall be carried out to determine the load resistance $F_{test,R}$. Only one test shall be carried out on a specimen nominally identical with the series manufacture. The minimum test load shall be determined from:

$$F_{test,R} > \boxed{1{,}05} \cdot F_{R,d}$$

where $F_{R,d}$ = design load for the ultimate limit state.

Alternatively, when the test has been continued up to failure, the results may be used for analysis by recalculating the design strength with the actual characteristics of the specific element that led to damage.

7.5 Timber poles

7.5.1 General

The requirements of ENV 1995-1-1 shall be complied with, except where otherwise specified in EN 12465, EN 12479, EN 12509, EN 12510 and EN 12511.

7.5.2 Basis of design

1) The rules given in clause 3 “Basis of design” are applicable.
2) Unless otherwise specified, it is not necessary to consider seismic effects, fatigue design or design and construction for fire resistance.

7.5.3 Materials

1) Materials shall comply with 7.2
2) Only timber in its original “as-felled” condition is considered. Sawn or laminated and glued timber is not covered in this standard.

7.5.4 Serviceability limit states (refer also to NNAs)

1) Serviceability limit states for timber poles are deformations or deflections, which may affect the appearance or the effective use of the structure.
2) The serviceability limits are related to the tower geometry and shall be defined in compliance with the required electrical clearances (to ground and to structure) as given in clause 5 “Electrical requirements”.

7.5.5 Ultimate limit states

7.5.5.1 Basis

1) Timber poles and components shall be so proportioned that the basic design requirements for ultimate design state given in clause 3 "Basis of design" are satisfied.

2) The partial safety factors γ_M shall be taken as follows:

— resistance of cross sections and elements	$\gamma_{M\,1}$	=	1,50
— resistance of bolted connections	$\gamma_{M\,b}$	=	1,25

3) The design of the timber pole shall be such that the deflection at the top at the ultimate limit state does not exceed 10 % of the height of the pole above ground level.

7.5.5.2 Calculation of internal forces and moments (Chapter 5.2)

1) The internal forces and moments in any transverse section of the structure shall be determined using elastic global analysis.

2) If the flexibility of the structure makes it necessary, the second order theory, taking into account the influence of the deformation of the structure, shall be used for the global analysis of timber poles.

3) Global elastic analysis shall be based on the assumption that the stress-strain behaviour of the material is linear, whatever the stress level.

4) In guyed timber structures the simultaneous compression and bending of the tower leg shall be taken into account using the measured or maximum allowable initial out of straightness. Measured values (if available) of the pole dimensions may also be used instead of the standard table values given in different NNAs. The allowable out of straightness of the pole is specified as follows: "a straight line drawn from the centre of the tip to the centre of the butt shall lie inside the pole".

7.5.5.3 Resistance of members

1) The resistance of timber poles against tension, compression and bending shall be determined in accordance with the requirements of ENV 1995-1-1

7.5.6 Resistance of connections

1) All connections shall have a design resistance such that the structure remains effective, and that the basic design requirements given in clause 3 "Basis of design" are satisfied.

2) The design resistance of bolts in shear or tension is given in annex J.

7.5.7 Design assisted by testing (Chapter 8)

Experimental verification by a full-scale test may be required to validate the calculated resistance of either a complete timber pole or a part of the structure. The full-scale test shall be carried out to determine the load resistance $F_{test\,,\,R}$. Only one test shall be carried out on a specimen nominally identical with the series manufacture. The minimum test load shall be determined from:

$$F_{test\,,\,R} > \boxed{1{,}25} \cdot F_{R\,,\,d}$$

where $F_{R\,,\,d}$ = design load for the ultimate limit state.

Alternatively, when the test has been continued up to failure, the results may be used for analysis by recalculating the design strength with the actual characteristics of the specific element that led to damage.

7.6 Concrete poles

7.6.1 General

The requirements of ENV 1992-1-1 shall be complied with, except where otherwise specified in EN 12843.

This latter document is completed by the following clauses:

7.6.2 Basis of design

7.6.2.1 General rules

1) The rules given in clause 3 “Basis of design” are applicable.
2) Unless otherwise specified, it is not necessary to consider seismic effects, fatigue or fire resistance.

7.6.2.2 Design load

The horizontal design load is the load applied horizontally to a conventional section at a specified distance “d” from the top of the pole, and generally d = 0,25 m.

The value of this design load is such that its effect in terms of moment at the base of the pole is equivalent to the effect of the design live loads.

7.6.2.3 Lateral reinforcement

In order to control longitudinal cracking from several potential sources, lateral reinforcement is used. This reinforcement consists of lateral ties or spirals.

Potential sources of cracking may include the transversal forces, the concrete shrinkage, the thermal effects and the wedging effects due to prestressing loads near the ends of the pole.

7.6.3 Materials

Materials shall comply with 7.2 and with EN 12843.

7.6.4 Serviceability limit states (refer also to NNAs)

1) The partial factor for actions shall be taken as follows:

— prestressing force γ_{Pt} = $\boxed{1,00}$

2) The design values are defined as follows:

— maximum deflection (where H is the total pole length) = $\boxed{0,025}$ H

— maximum width of cracks, in case of reinforced concrete = $\boxed{0,3}$ mm

Tensile stresses in the concrete of prestressed concrete poles are not permitted under permanent working loads as well as under loads less than or equal to 40 % of maximum working loads,

7.6.5 Ultimate limit states

1) Concrete poles and components shall be so proportioned that the basic design requirements for ultimate design state given in clause 3 "Basis of design" are satisfied.

2) The partial factor for actions shall be taken as follows:

— prestressing force γ_{Pt} = $\boxed{0,90}$ or $\boxed{1,20\ *}$

(* depending whether the action is favourable or not for the calculated effect)

3) The partial safety factors γ_M shall be taken as follows:

— concrete $\gamma_{M\,C}$ = $\boxed{1,50}$
— steel (ordinary or prestressed) $\gamma_{M\,S}$ = $\boxed{1,15}$

As far as elements subjected to quality control are concerned, lower values of $\gamma_{M\,C}$ and $\gamma_{M\,S}$ may be taken.

7.6.6 Design assisted by testing

Experimental verification by a full-scale test may be required to validate the calculated resistance of either a complete concrete pole or a part of the structure. The full-scale test shall be carried out to determine the load resistance $F_{test\,,\,R}$. Only one test shall be carried out on a specimen nominally identical with the series manufacture. The minimum test load shall be determined from:

$$F_{test\,,\,R} > \boxed{1,30} \cdot F_{R\,,\,d}$$

where $F_{R\,,\,d}$ = design load for the ultimate limit state.

Alternatively, when the test has been continued up to failure, the results may be used for analysis by recalculating the design strength with the actual characteristics of the specific element that led to damage.

In addition, the maximum deflection at serviceability limit states and the residual deflexion after releasing the load shall comply with the following criteria:

— maximum deflection after permanent loading for 15 min at serviceability limit state (where H is the total pole length) = $\boxed{0{,}012\,5}$ H

— maximum residual deflection = $\boxed{0{,}003}$ H

7.7 Guyed structures

7.7.1 General

A guyed support can be a lattice steel structure or a pole of tubular steel, concrete or timber with guys of galvanised extra high strength steel wire strands. Various types of configurations exist such as V-tower, portal, column, catenary, double guyed timber leg structures, multi-level guyed tubular leg structures, etc.

The requirements of parent Eurocodes shall be complied with, except where otherwise specified below.

7.7.2 Basis of design

1) The rules given in clause 3 "Basis of design" are applicable.

2) Unless otherwise specified, it is not necessary to consider seismic effects, fatigue design or design and construction for fire resistance.

7.7.3 Materials

1) Materials shall comply with 7.2 and documents relative to parent single supports

7.7.4 Serviceability limit states

1) The serviceability limits are related to the tower geometry and shall be defined in compliance with the required electrical clearances (to ground and to structure) as given in clause 5 "Electrical Requirements".

7.7.5 Ultimate limit states

7.7.5.1 Basis

1) Guyed structures and their components shall be so proportioned that the basic design requirements for ultimate design state given in clause 3 "Basis of design" are satisfied

2) The partial safety factor γ_M shall be taken as specified in the parent support, and in addition:

   — resistance of guys to ultimate strength $\gamma_{M\,2}$ = $\boxed{1{,}60}$

3) The guyed structure shall generally be analysed using the second order theory. Embedded guyed supports with pre-tensioned guys and other simple structures are often stiff enough to allow the use of the first order theory.

4) The analysis shall be based on the assumption that the stress-strain behaviour of the material is linear.

7.7.5.2 Calculation of internal forces and moments

A latticed column (leg or crossarm) shall be analysed for bending and buckling using a 3-dimensional pin ended member model or a 3-dimensional beam model where the axial and bending stiffness shall be calculated from the main member properties while the torsional stiffness shall be derived from the bracing member properties.

Torsional-flexural buckling of cold formed profiles shall be checked. Local buckling of main legs and bracing members shall be taken into account.

The use of diagonal bracings shall prevent the possible distortion of a square cross section.
Shear force distribution shall be taken into consideration when calculating member forces at both ends of a hinged latticed column. To consider imperfections in the column an additional force acting transverse to the column may be added.

7.7.5.3 Second order analysis

Guyed poles shall be designed for bending and buckling. For tubular steel poles the local buckling shall be analysed according to 7.4.

In the second order analysis the following aspects shall be taken into account:

An initial out of straightness shall be assumed for sections hinged at both ends (tower legs). A normal design value is L/600 for steel sections and L/150 for timber sections, where L is the length of the leg. Smaller values (not less than L/1 000) may be used, if these are based on measurements. The out of straightness shall be applied in the most unfavourable direction considering the response or stress concerned. Embedded guyed supports shall be analysed using an initial out of straightness or inclination.

The slackening of one or more guys at different loading conditions shall be taken into consideration.

An eccentricity tolerance of 20 mm (in addition to the design eccentricity value) at the ends of a hinged lattice leg shall be applied when calculating bending stresses in the compression leg. The tolerance shall act in the most unfavourable direction considering the response or stress concerned. A smaller value may be used, if this is based on measurements.

If an end eccentricity at the ends of hinged lattice legs is used to compensate for the bending effects of the wind load on the leg, the following additional special load case shall be checked: Maximum wind on conductors and other tower sections but reduced wind on the compression leg.

7.7.6 Design details for guys

The characteristic resistance of the guy shall be the nominal value for ultimate breaking strength specified in appropriate standards. The effective elastic modulus of the guy determined from standard, manufacturer or test may be used in analysis.

Galvanised steel wire strands or steel ropes with steel core shall be used for the guys. To withstand high fault current in the guy the steel wires can be complemented with aluminium wires, type $AL1/ST_{YZ}$.

The guys shall be equipped with devices for retightening. The connection between the guy rope and the anchor device shall be accessible. The connections and tightening devices shall be secured against loosening in service.

The guys used in structures such as V-tower, portal, catenary and double-guyed timber leg tower are generally pretensioned to a small force after the erection of the structure. The effect of this force, usually not greater than 20 kN, may be neglected in the calculations.

The guys used in other structures are generally pretensioned to a specified value in order to reduce the deformation at extreme loads. The pretensioning stress shall be specified as a percentage of the breaking or maximum stress. The angle towers shall be vertical after the stringing of the conductors at the yearly mean temperature (Every Day Temperature).

At guyed towers where tubular sections are used as legs, crossarms or horizontals, special attention shall be paid to preventing possible vibration, galloping and fluttering phenomena.

Where cast steel sockets or cast wedge sockets are used in the guy terminations, freedom from defects in the casting should be ensured by an acceptable non-destructive test or manufacturer's certificate.

The actual out of straightness of the tower leg shall be checked by inspection before erection and shall comply with the design value.

The possible pre-tensioning of the guys shall be checked and maintained during periodical inspections. For a multi-level guyed support, instructions for the erection work are needed because the structure is sensitive to the pretensioning of the guys.

Due care shall be taken for protection of the guy in populated areas for possible galvanic corrosion and possible flashover. In some cases, insulation of the guy can be recommendable. Also a slackened or loose condition caused by the wind, maintenance or other event shall be considered.

In order to minimise the possibility of guy vibrations the pretension should be less than 10 % of the breaking load of the guy.

7.8 Other structures

1) Other structures shall be designed in accordance with the requirements of the parent Eurocodes: ENV 1992-1-1, ENV 1993-1-1 and ENV 1995-1-1.

2) The analysis and the design of other specific structures not covered by the above subclauses shall be agreed between the client and the designer/manufacturer prior to the commencement of the contract.

7.9 Corrosion protection and finishes

7.9.1 General

The supports shall be protected against corrosion in order to fulfil their intended working life according to clause 3 "Basis of design", taking into account the intended maintenance regime. The following subclauses include minimum requirements, but enhanced requirements, including compliance with local environmental regulations, may be included in the NNAs or the project specification.

7.9.2 Galvanising

Unless otherwise stated in the project specification, after completion of all fabrication procedures, all steel material shall be hot-dip galvanised and tested in accordance with EN ISO 1461. The coating mass (unless otherwise stated) shall be in accordance with the requirements of EN ISO 1461.

All steel materials prior to galvanising shall be free from any substance or impurities, which may adversely affect the quality of finish. The preparation for galvanising and the galvanising itself shall not adversely affect the mechanical properties of the coated material. All bolts, screwed rods and nuts, including the male threaded portions, shall be hot-dip galvanised (see EN ISO 1461 – C.2.2).

7.9.3 Metal spraying

Unless otherwise stated in a project specification, when pieces are too large or difficult to galvanise, they shall be protected against corrosion by thermal spraying a zinc coating over the base metal, performed according to EN ISO 14713 and in accordance with EN 22063. Zinc deposit thickness shall be not less than 80 µm. When this system is used, the inside surface of hollow sections shall also be protected.

7.9.4 Paint over galvanising in plant (Duplex system)

When a paint coating is to be applied in plant after hot-dip galvanising of steel structures, this coating shall be done as soon as possible.

The coating material should be lead-free according to national general employee protection regulations. Recommended materials, giving an excellent adherence to new galvanised steel, should preferably be mono-component materials in a base of vinyl or acrylic copolymers in aqueous dispersion. Usually single layer coatings are applied with dried out thickness of 70 µm to ensure proper protection.

If required by the technical chart of the coating material supplier, the galvanised steel parts shall be shot blasted before coating. As blasting material corundum or granules of high grade steel with a size of 0,25 mm to 0,50 mm should be used for best results. The blasting pressure and distance are determined so that the maximum thickness of zinc blasted away is 10 µm.

The zinc surface of all parts, which are to be coated, shall be dust-free, oil-free and free from all foreign substances as well as free from all zinc corrosive products. These parts shall be coated immediately after surface treatment. Surface preparation and actual painting shall be carried out indoors.

After coating, the part number on each construction part shall remain legible for proper erection work. Connecting parts like gusset-plates need not be coated.

The drying out of coated construction parts shall be carried out sufficiently in the plant, so that no damage to the coated surfaces can arise through transport. In order to avoid transport damage, pieces of double-sided aluminium-coated cardboard or equivalent material shall be inserted between each individual section.

It should be taken into consideration, that the bundle weight of the coated construction parts should be determined so that the parts, which are on the bottom, do not suffer damage due to pressure.

After assembling of supports all uncoated parts (bolts, nuts, gusset-plates, etc.) or parts with damage to the coating shall be coated on site.

7.9.5 Decorative finishes

For daytime aircraft warning systems, attention is drawn to the fact that the paint system used shall be compatible with the underlying surface finish. Due reference to International Civil Aviation Organisation (ICAO) Regulations - annex 14 or local regulations shall be included in the NNAs or the project specification.

7.9.6 Use of weather-resistant steels

The use of weather resistance steels requires special design considerations and full-scale experience. They should be used with caution in areas where limited corrosion occurs since some corrosion is necessary to provide the weathering layer.

7.9.7 Protection of timber poles

The timber shall be protected from deterioration by impregnation with salt or creosote or other approved preservative agents against rotting, birds and insects. The protection affects the design parameters by increasing the service life of the timber.

Particular attention shall be given to bore holes and scarfings, whether they are made before or after installation.

7.10 Maintenance facilities

7.10.1 Climbing

Facilities to allow safe access by authorised personnel shall be as stated in the project specification and/or in the NNAs. Where appropriate, this shall include access for live line maintenance. Access to pole cross-arms shall be made preferably by a lightweight, removable device, designed to support the required loads.

Account shall be taken of the requirements to prevent unauthorised access to supports as specified in 7.10.3.

7.10.2 Maintainability

In addition to climbing attachments, the provision of other attachments/holes for installation of maintenance equipment shall be as stated in the project specification and/or in the NNAs.

7.10.3 Safety requirements

The requirements and methods of providing for the following shall be as stated in the project specification and/or in the NNAs and shall take into account relevant national (and international) legal obligations such as

— provision of safety information for the general public (e.g. warning signs, telephone number for emergency contact).
— prevention of unauthorised climbing.
— provision of aids to authorised personnel to enable them to correctly identify energised and de-energised conductors (e.g. circuit identification markings).
— provision for bonding of earthwire and earthing of support.

7.11 Loading tests

Loading tests on overhead lines supports shall be carried out in accordance with IEC 60652.

7.12 Assembly and erection

The workmanship for assembly and erection shall be in conformity with the minimum requirements of ENV 1992-1-1, ENV 1993-1-1, ENV 1995-1-1 and ENV 1090-1.

8 Foundations

8.1 Introduction

This clause gives only an outline of the geotechnical aspects of foundations for transmission towers. It will be reconsidered when more experience with the application of ENV 1997-1-1 is available.

Foundations fulfil the task of transferring the structural loads from the support to the subsoil, as well as protecting the tower against critical movements of the subsoil.

Foundations for supports may take the form of single foundations or separate footings for each leg.

The loading on single footings is predominantly in the form of overturning moment, which is usually resisted by lateral soil pressure, together with additional shear and vertical forces resisted by upwards soil pressure.

Common types of single foundations are monobloc footings, pad or raft footings, grillage footings, caisson or pier foundations, and single pile or pile group foundations.

When separate footings are provided for each leg the predominant loadings are vertical downward and uplift forces. Uplift is usually resisted by dead weight of the foundation bulk, earth surcharges and/or shear forces in the soil. This also applies to guy foundations. Compression loads are countered by the soil resistance.

Common types of separate footing foundations are (stepped) block footings with or without undercut ("pad and chimney", spread footings), auger bored footings with or without expanded base, pier or caisson foundations, grillage foundations and vertical or raked pile foundations.

8.2 General requirements

The foundations of supports shall be capable of transferring the structural loads resulting from the actions on the support into the subsoil with sufficient reliability.

The following items should be taken into consideration when designing foundations:

- design loads and design formulae ;
- configuration of the foundation ;
- limiting values of displacements ;
- geotechnical design parameters taking into account ground water levels ;
- design parameters for structural materials ;
- support/foundation interconnections ;

- foundation construction and installation ;
- ground water levels ;
- special loads (avalanche, creeping snow, landslide, earthquake, shocks, etc.).

Generally, both ultimate limit states and serviceability limit states shall be checked for the design of foundations.

Proof of the suitability of foundations by loading tests may also be requested. This suitability may also be established by the satisfactory behaviour of existing similar foundations.

8.3 Soil investigation

Prior to determination of the type of foundation, and its form and dimensions, the structure of soil below the surface down to a depth of at least the effective width of the foundation, and in the case of a piled foundation, greater than the pile tip depth, must be known in sufficient detail. Natural risks shall also be considered in the choice of the type of foundation.

Geotechnical investigations shall be planned taking into account the type of foundation and the required parameters for the design of the foundation.

The soil investigations shall be carried out to such a depth that all layers, which significantly influence the foundation strength, are included. When determining the extent and depth of soil investigations, information already available concerning the pattern, uniformity and characteristics of the individual layers should be taken into consideration. Where justified, further soil investigation may be omitted.

The type, condition, extent, stratification and depth of the soil layers as well as ground-water conditions can be examined by boring, sounding such as Cone Penetration Test (CPT), Standard Penetration Test (SPT), penetrometer, trial pits or other standardised tests, if available knowledge does not provide sufficient information. The results of the soil investigations shall be recorded, in accordance with relevant standards or codes of practice.

In the absence of better information from soil investigations, the soil parameters stated in Tables M.2 and M.3 may be used for initial design. In this case, it shall be confirmed by inspection or testing, during construction, that the soil parameters used are appropriate.

When backfilling is used, sufficient compaction shall be ensured when adopting these values. In certain circumstances a possible reduction of consistency of cohesive soils should be taken into account in the calculation. When backfilling with granular soil in cohesive soil, the tendency of water to accumulate in the backfill shall be considered. In certain circumstances, if it is not possible to assure sufficient compaction, lower values shall be used.

8.4 Loads acting on the foundations

Loads on foundations shall be assessed taking into account the most critical structural loads on the foundations resulting from the design of the supports, and it shall be clearly identified whether they are inclusive or exclusive of any partial safety factors (see 3.7.2).

The design loads shall be relevant to the required combinations of applied loading cases, as stated in clause 4 (Table 4.2.7), or in the respective NNAs, or in the Project Specification.

8.5 Geotechnical design

8.5.1 General

This subclause gives only an outline of the general principles, which apply when designing support foundations. Reference should be made to the respective NNAs for specifications on geotechnical design methods and formulas.

8.5.2 Geotechnical design by calculation

8.5.2.1 General design formula

The calculation model shall describe the behaviour of the ground for the limit state in consideration.

Wherever possible, the calculation model should be correlated with field observations of previous designs, model tests or more reliable analyses.

The formulae to be used to determine the foundation resistance are those given in the appropriate code of practice, as given in ENV 1997-1-1, or in the NNAs, or in the relevant literature, or those which have been used with satisfactory practical experience.

It should be noted that the partial safety factors used for soil pressure, uplift, etc. may depend on the method of analysis. They may be indicated in the NNAs.
Prior to their use, it shall be established whether the foundation design models provide mean foundation resistances or characteristic foundation resistances. If the former applies, the characteristic resistance shall be determined by appropriate conversion.

The general design formula has the form of

$$E_d \leq \frac{R_k}{\gamma_M} = f\{X_{1d}, X_{2d}, \ldots\}$$

where :

E_d is the design value of structural load
R_k is the characteristic value of foundation resistance
γ_M is the partial coefficient for the resistance
$f\{X_{1d}, X_{2d}, \ldots\}$ (see 3.7.2, 3.7.3 and 3.7.4)

8.5.2.2 Geotechnical parameters

The geotechnical parameters to be used in the design may be either assessed directly from the results of soil investigations or assumed in accordance with the type of a soil encountered.

The characteristic value of a soil or rock property may be based on the results of laboratory and field tests. It should be selected as a conservative estimate of conditions affecting the specific site.

If ground water is present the reduction of resistance of the foundation shall be considered assuming the most unfavourable ground-water table.

8.5.2.3 Displacements

The design values for the limiting movements depend on the type of foundations and on the supported tower structure.

NOTE As a guidance, damage and failure limits given in IEC Report 60826 may be adopted.

8.5.3 Geotechnical design by prescriptive measures

In situations where calculation models are not available or unnecessary, the design may be done by the use of prescriptive measures confirmed by experience. These involve conventional and generally conservative details in the design, and attention to specification and control of materials, workmanship, and maintenance procedures.
The foundation of self-supporting timber poles in medium or good soils can be performed according to the sample rule:

"Self supporting timber poles shall be erected using direct embedment in the ground. The depth shall be at least 1/7 of the pole length and not less than 1,5 m. The excavation shall be filled with gravel and stones, which shall be carefully compressed to ensure the lateral rigidity of the embedment. Concrete may be used if there is no risk of standing water."

8.6 Loading tests

Loading tests or tests on experimental models form a valuable method for justifying the design of foundations or to test the strengths of individual foundations, whether test or production foundations.

Three categories of tests are defined: Proof tests, Design tests and Research tests.

When proof tests are undertaken on production foundations they shall successfully pass the test at a percentage of the design load such that they remain fully serviceable after testing.

Design or Research tests are carried out on especially installed foundations typically up to failure. Design tests are intended to verify specific design approaches or assumptions for the geotechnical parameters. According to the aim of these tests the efforts for accuracy of installation and monitoring the test are high. The evaluation shall be carried out on a scientific basis, making provision for the following factors:

- loading conditions;
- difference in the ground conditions between the test and the actual construction;
- duration of test loading;
- scale effects, especially if smaller models are used;
- climatic effects.

Details concerning the preparation of the test, the testing arrangement, the test procedure and evaluation are given in EN 61773.

8.7 Structural design

Structural design parameters and methods shall generally conform to the appropriate European standard and/or NNAs.

Details of the proposed method of interconnection between the support and the foundation shall be as stated in NNAs and/or in the Project Specification.

Due consideration should be given to the design of the interconnection where fatigue has an influence.

The specifications for materials used in the construction of the foundation, e.g. concrete and its constituent materials, structural and reinforcing steel, shall be in accordance with ENV 1992-1-1, ENV 1993-1-1 and/or NNAs. For steel and anchor bolts, the recommendations given in 7.2 should be considered.

8.8 Construction and installation

Foundations shall be constructed or installed in accordance with ENV 1992-1-1 and ENV 1997-1-1 and/or NNAs.

Prior to the start of the construction, a plan of contingency actions should be devised which may be adopted if digging reveals soil characteristics or behaviour outside acceptable limits.

Adequate supervision should always be ensured during foundation construction.

If backfill is used its compaction shall be carried out carefully in order to achieve soil characteristics as close as possible to those of the undisturbed soil (see 8.3).

The construction shall be recorded. Examples for installation records may be taken from EN 61773. Where appropriate, any restrictions on foundation installation techniques and associated dimensional tolerances on completion shall be stated in the Project Specification.

9 Conductors and overhead earthwires (ground wires) with or without telecommunication circuits

9.1 Introduction

This clause gives the requirements for conductors and earthwires with or without telecommunication circuits which are attached to overhead line supports.

Conductors and earthwires shall be designed, selected and tested to meet the electrical, mechanical and telecommunications requirements as defined by the line design parameters. Consideration shall also be given to the necessary protection against fatigue due to vibration. Design life may be subject to agreement between the supplier and the purchaser

NOTE 1 In the following subclauses the term "conductor" should be taken to include "earthwires" and where appropriate conductors and earthwires with telecommunication circuits.

NOTE 2 This standard does not apply to wrapped cables or all dielectric self supporting (ADSS) telecommunication cables. Similarly it does not include metal clad telecommunication cables which are not used as earthwires.

9.2 Aluminium based conductors

9.2.1 Characteristics and dimensions

Conductors shall be manufactured from round or shaped wires of aluminium or aluminium alloy and can contain zinc coated steel wires or aluminium clad steel wires for strengthening. Earthwires shall be designed to the same standards as phase conductors.

Homogeneous round wire conductors, both all aluminium (AL1) and all aluminium alloy (ALx), and composite round wire conductors, aluminium or aluminium alloy conductor steel reinforced (AL1/STyz or ALx/STyz), aluminium or aluminium alloy conductor aluminium clad steel reinforced (AL1/SAyz or ALx/SAyz) and aluminium conductors aluminium alloy reinforced (AL1/ALx) shall be designed according to EN 50182.

For conductors with cross-sectional aluminium area in excess of 50 mm² it is recommended that the diameter of the outer layer round wires should not be less than 2,33 mm.

Material specifications for wire used in these conductors shall be according to EN 50183, EN 50189, EN 60889 and EN 61232 and the design arrangements shall be specified in the Project Specification or agreed by the purchaser with the supplier.

NOTE 1 An IEC standard (IEC 62219) dealing with aluminium and aluminum alloy wires shaped before stranding is in preparation.

NOTE 2 For some projects types of conductors or materials not included in existing EN standards may be used in overhead line construction. In such cases, and in the absence of definitive standards, the Project Specification should specify all the required characteristics together with the relevant methods of test, making reference as appropriate to EN standards.

When materials are used which differ from those in the referenced standards their characteristics and their suitability for each individual application shall be verified as specified in this standard or in the Project Specification.

The design of a conductor, including its construction and the characteristics of the materials, shall take into consideration the effect of permanent elongation (creep) on the conductor sag.

NOTE 3 Guidance on the methods of design calculation, including an assessment of conductor creep and other characteristics, can be found in IEC 61597 and in EN 61395.

9.2.2 Electrical requirements

The resistivity of the aluminium or aluminium alloy wire shall be selected from the values in EN 50183 and EN 60889. The DC resistance of the conductor at 20 °C shall be calculated according to the principles of EN 50182.

The resistances of a preferred range of round wire conductors are given in EN 50182.

For conductors with different wire sections the conductor resistance shall be calculated using the resistivity of the wire, the cross-sectional area and stranding parameters of the conductor.

The current carrying capacity (ampacity) and the performance under short circuit conditions, particularly the effect on strength, shall be verified against the requirements of the Project Specification. Consideration shall also be given to the predicted radio noise level and audible noise level of conductors for higher voltage systems against the requirements of the Project Specification (see 5.5.1 and 5.5.2).

9.2.3 Conductor service temperatures and grease characteristics

The maximum service temperatures of aluminium based conductors under different operating conditions shall be specified either in the NNAs or in the Project Specification. This shall give some or all of the requirements under the following conditions:

— maximum service temperature at normal line loading;
— maximum short duration temperature for specified times at different line loading(s) above the normal level;
— maximum temperature due to a specified power system fault.

NOTE 1 The use of certain special alloys generally permits the use of higher service temperatures.

NOTE 2 Information on the calculation of temperature rise due to short circuit currents is given in EN 60865-1. Alternatively and with suitable precautions the actual temperature rise due to short circuit currents may be measured during a test.

The Project Specification shall specify the characteristics of the conductor grease to allow for the maximum conductor temperature during normal service and during short duration overloads following a power system fault.

NOTE 3 Greases containing soap additives and soap free greases are available. These two types of greases possess different performance characteristics, the most important of which are the oil separation point and the drop point. In the case of soap free greases the drop point may not necessarily exceed 100 °C.

NOTE 4 Further information concerning greases and their application is given in EN 50326.

9.2.4 Mechanical requirements

The rated tensile strengths of aluminium based conductors, calculated in accordance with EN 50182 shall be sufficient to meet the loading requirements determined from clause 4 in conjunction with the partial factors for conductors given in 9.6.2.

When considered necessary, the maximum permissable tensile load in the conductor shall be specified either in the NNAs or in the Project Specification.

9.2.5 Corrosion protection

The purchaser and supplier shall agree the requirement for corrosion protection of conductors, which may include grease and/or zinc coating or aluminium cladding of steel wires.
Grease, when used, shall comply with the requirements of EN 50326. The Project Specification shall specify the type and required amount of grease to be applied during stranding of the conductor. Normally this shall be selected from one of the cases defined in annex C of EN 50182. For voltages in excess of 100 kV grease shall not be applied to the outer layer of wires of the conductor. The properties of the grease shall not allow its migration to the conductor surface during its service life.

The requirements for coating or cladding of steel wires with zinc or aluminium shall be specified in the Project Specification by reference to EN 50189 or EN 61232, as appropriate.

9.2.6 Test requirements

The test requirements for aluminium based conductors shall be as specified in EN 50182.

NOTE The Project Specification may also specify requirements for a conductor creep test, or an elastic modulus test.

9.3 Steel based conductors

9.3.1 Characteristics and dimensions

Information relevant to constructional methods is given in EN 50182. Material specifications are given in EN 50189 for zinc coated steel wire and EN 61232 for aluminium clad steel wire.

NOTE See also the notes to 9.2.1.

9.3.2 Electrical requirements

The resistivity of zinc coated steel wires is given for calculation purposes in EN 50189 and specified for aluminium clad steel wires in EN 61232. The DC conductor resistance at 20 °C shall be calculated according to the principles of EN 50182.

NOTE See also 9.2.2. in relation to ampacity, short circuit performance and radio noise level when relevant to the conductor design.

9.3.3 Conductor service temperatures and grease characteristics

The maximum service temperatures of steel based conductors under different operating conditions shall be specified either in the NNAs or in the Project Specification. This shall give some or all of the requirements under the following conditions:

— maximum service temperature at normal line loading;
— maximum short duration temperature for specified times at different line loading(s) above the normal level;
— maximum temperature due to a specified power system fault.

The Project Specification shall specify the characteristics of conductor grease taking into account the service temperatures.

NOTE: See also the notes to 9.2.3.

9.3.4 Mechanical requirements

The rated tensile strength of steel based conductors, calculated in accordance with the principles given in EN 50182, or the relevant national standards, shall be sufficient to meet the loading requirements determined from clause 4 in conjunction with the partial factors for conductors given in 9.6.2.

When considered necessary, the maximum permissable tensile load in the conductor shall be specified either in the NNAs or in the Project Specification.

9.3.5 Corrosion protection

The purchaser and supplier shall agree the requirement for corrosion protection of steel based conductors which may include grease and/or zinc coating or aluminium cladding. The requirements for coating or cladding of steel wires with zinc or aluminium shall be specified in the Project Specification by reference to EN 50189 or EN 61232 as appropriate.

Grease, when used, shall comply with the requirements of EN 50326. The Project Specification shall specify the type and required amount of grease to be applied during stranding of the conductor. Normally this shall be selected from one of the cases defined in annex C of EN 50182. For voltages in excess of 100 kV grease shall not be applied to the outer layer of wires of the conductor and the properties of the grease shall not allow its migration to the conductor surface during its service life.

9.3.6 Test requirements

Steel based conductors shall be tested according to the relevant requirements of EN 50182 and of EN 50189 and EN 61232.

9.4 Copper based conductors

Conductors are generally constructed from round wires of copper or copper alloy according to relevant National Standards in the absence of any existing International Standards. Where appropriate, requirements shall be specified in the Project Specification.

9.5 Conductors (OPCON's) and ground wires (OPGW's) containing optical fibre telecommunication circuits

9.5.1 Characteristics and dimensions

The design characteristics of OPCON's and OPGW's with optical telecommunication fibres shall be specified in the Project Specification.

NOTE 1 Electrical, mechanical and physical requirements and test methods for OPGW are given in IEC 60794-4-1.

NOTE 2 All aspects of OPCON's and OPGW's are currently being studied by a Joint Working Group of CLC/TC 7 and CLC/TC 86 - Optical cables to be used on electrical power lines.
The standard EN 187200 has been published. Until further standards on the subject are published reference should be made to EN 60794-1-1 and EN 60794-1-2 for optical cables and EN 50182 for conductor requirements.

9.5.2 Electrical requirements

The DC resistance at 20 ^{0}C of an OPCON or OPGW shall be calculated using the resistivity of the individual aluminium, aluminium alloy, zinc coated steel or aluminium clad steel wires together with the appropriate stranding constant and the resistivity of other aluminium components of the conductor according to the requirements of IEC 60794-4-1 and/or the principles of EN 50182.

Reference shall be made in the Project Specification to the current carrying capacity and short circuit conditions, and, if appropriate, radio noise level.

9.5.3 Conductor service temperature

The maximum service temperatures of OPCON's and OPGW's shall be specified either in the NNAs or in the Project Specification. This shall give the maximum continuous temperature and the maximum short duration temperatures for specified times.

NOTE See also notes 1 and 2 to 9.2.3.

9.5.4 Mechanical requirements

The rated tensile strengths of OPCON's and OPGW's calculated according to the Project Specification, shall be sufficient to meet the loading requirements determined from clause 4 in conjunction with the partial factors for conductors given in 9.6.2.

When considered necessary, the maximum permissable tensile load in the conductor shall be specified either in the NNAs or in the Project Specification.

9.5.5 Corrosion protection

The Project Specification shall specify or the purchaser shall agree with the supplier the requirement for corrosion protection of OPCON's, which may be grease and/or aluminium cladding or zinc coating of steel strands.

9.5.6 Test requirements

The test requirements for OPCON's and OPGW's shall be as specified in EN 60794-1-2 and in the Project Specification.

9.6 General requirements

9.6.1 Avoidance of damage

The Project Specification shall specify the packaging and marking requirements for delivery of the conductor in accordance with EN 50182. The manufacturer shall also specify the minimum diameter to be used for the conductor stringing equipment (e.g. tensioner/puller bull wheels, running blocks etc) and any special stringing procedures or precautions required to avoid conductor damage and/or birdcaging.

The purchaser shall also ensure that requirements for conductor fittings e.g. selection, positioning and installation are adequately specified to avoid the risk of birdcaging.

9.6.2 Partial factor for conductors

The partial factor applied to the rated tensile strength for all types of conductors when either the General approach or the Empirical approach (see clause 3) is used shall have a minimum value of:

$$\boxed{\gamma_M = 1{,}25}$$

A different value for the partial factor may be specified in the NNAs.

9.7 Test reports and certificates

The results of all type tests shall be reported in certificates issued by the supplier or a qualified organisation. These shall be valid without time limit provided that there is no change in materials, construction, method of manufacture or manufacturer of the conductor.

The results of sample tests shall be reported in a certificate issued by the supplier for each lot delivered.

9.8 Selection, delivery and installation of conductors

Information relating to the selection, delivery and installation of conductors is given in annex N.

10 Insulators

10.1 General

The insulator designs include strings of string insulator units of the cap and pin and long rod types and line post insulators. These may be manufactured using ceramic material or glass, or produced as composite insulators. On some overhead lines combinations of these insulators may be used.

NOTE All these types of insulators are covered by EN and/or IEC Publications except composite line post insulators which are under study in IEC SC 36B.

Insulators shall be designed, selected and tested to meet the electrical and mechanical requirements as determined by the design parameters of the overhead line. Design life may be subject to agreement between the supplier and the purchaser.

Insulators shall be resistant to the influence of all outdoor climatic conditions including solar radiation. They shall be resistant to atmospheric pollutants and be capable of satisfactory performance when subjected to the pollution conditions specified in the Project Specification.

Insulators shall be designed for ease of maintenance including, when specified, maintenance under live line conditions.

10.2 Standard electrical requirements

The design of insulators shall be such that the required electrical withstand voltages (see 5.3) are achieved. These requirements are summarised in Table 10.2.

Table 10.2 - Standard electrical requirements

Voltage range	45 kV < $U_s \leq$ 245 kV				U_s > 245 kV		
Insulator type	Insulator sets				Insulator sets		
	Cap and pin[a]	Long rod[a]	Compo-site[b]	Line post[a]	Cap and pin[a]	Long rod[a]	Compo-site[b]
Wet power frequency withstand voltage	X	X	X	X	-	-	-
Dry lightning impulse withstand voltage	X	X	X	X	X	X	X
Wet switching impulse withstand voltage	-	-	-	-	X	X	X
Puncture withstand voltage (single unit)	X	-	-	X[c]	X	-	-

[a] Tests carried out to EN 60383-1 and EN 60383-2.

[b] Tests carried out to IEC 61109 (applicable to insulator units only).

[c] For those line post insulators which are not puncture proof

10.3 RIV requirements and corona extinction voltage

All types of insulators for overhead lines shall, under test conditions, only produce levels of radio interference consistent with the overall level specified for the installation. The visible corona extinction voltage shall, when applicable, be specified. Further information on corona effect, including radio interference, is given in 5.5.

When type tests are required they are normally performed on complete insulator sets or on line post insulators. The purchaser shall specify the applied voltage and the corresponding maximum radio interference voltage and if required the minimum visible corona extinction voltage. Tests shall be carried out in accordance with the requirements of EN 60437.

When type and/or sample tests are required on string insulator units they shall be carried out in accordance with EN 60437.

10.4 Pollution performance requirements

When required by the Project Specification insulators shall comply with the specified pollution performance requirements. Guidance on the design and selection of ceramic and glass insulators for use in polluted conditions is given in IEC 60815. In the case of insulators of ceramic material or glass, the purchaser shall specify the pollution performance requirements for insulator sets and line post insulators in accordance with one of the procedures described in EN 60507, or, alternatively, specify the minimum creepage distances, both total and protected. The protected creepage distance, when required, shall be specified and measured using a 90° angle to the axis of the insulator.

NOTE A pollution performance test for composite insulators is currently being studied by IEC TC 36 and CIGRE 33.04.

10.5 Power arc requirements

When required by the Project Specification insulator sets and line post insulators of all types shall comply with the specified power arc requirements. The purchaser shall state whether a power arc test is required. Information on power arc tests is given in IEC 61467.

The purchaser and supplier shall agree the relevant procedure for a test.

10.6 Audible noise requirements

When required by the Project Specification all types of overhead line insulators shall be designed so that they comply with the audible noise requirements specified for the installation. Further information concerning audible corona noise is given in 5.5.2.

10.7 Mechanical requirements

Insulators shall comply with the specified mechanical design requirements. The partial factor for all types of insulators shall have a minimum value when the Empirical approach (see clause 3) for design is adopted of:

$$\boxed{\gamma_M = 2,0}$$

A higher value of the partial factor may be specified in the Project Specification.

When the General approach for design is adopted different values, including lower values, may be specified in the NNAs.

The partial factor shall be applied to the specified mechanical or electro-mechanical failing load according to EN 60383-1 or IEC 61109. The relevant acceptance criteria shall be used for type and sample tests.

10.8 Durability requirements

10.8.1 General requirements for durability of insulators

The durability of an insulator is influenced by the design, the choice of materials and the manufacturing procedures. All materials used in the construction of insulators for overhead lines shall be inherently resistant to atmospheric corrosion which can affect their performance.

An indication of the durability of string insulator units of ceramic material or glass can be obtained from the thermal-mechanical test as specified in EN 60383-1. In special cases it may be necessary to consider fatigue characteristics by means of suitable tests specified in the Project Specification or agreed between the purchaser and the supplier.

NOTE Background information concerning the thermal-mechanical test is given in IEC/TR 60575.

10.8.2 Protection against vandalism

Special precautions may be necessary to combat the effects of vandalism. When specified in the Project Specification, the supplier shall offer methods to improve the performance and to meet the relevant requirements.

NOTE Information relating to impact testing of string insulator units of the cap and pin type is given in ANSI C29.1: American National Standard for electrical power insulators – Test methods and ANSI C29.2: American National Standard for electrical power insulators – Wet process Porcelain and Toughened Glass – Suspension Type.

10.8.3 Protection of ferrous materials

All ferrous materials, other than stainless steels, used in overhead line insulators shall be protected against corrosion due to atmospheric conditions. The usual form of protection shall be hot dip galvanising which shall meet the test requirements specified in EN 60383-1.

For installation in especially severe conditions, either an increased thickness of zinc may be specified in the Project Specification, or other methods agreed between the purchaser and the supplier. In these cases the methods of test to demonstrate the enhanced corrosion resistance shall also be agreed.

NOTE Reference may also be made to EN ISO 1461.

10.8.4 Additional corrosion protection

When specified in the Project Specification or recommended by the supplier and agreed by the purchaser the pins of cap and pin type string insulator units shall be fitted with zinc sleeves for additional corrosion protection. The purchaser and supplier shall agree the specification for the sleeve which shall include details of the mass, shape, zinc purity and degree of bonding.

NOTE Suitable test methods are given in EN 61325

10.9 Material selection and specification

Materials used in the manufacture of overhead line insulators shall be selected having regard to the relevant electrical, mechanical and durability requirements. The manufacturer shall ensure that the specification and quality control of materials is sufficient to ensure continuous achievement of the specified characteristics and performance requirements.

Locking devices used in the assembly of insulators shall comply with the requirements of IEC 60372.

NOTE When selecting the grade of malleable cast iron, including spheroidal graphite iron, consideration should be given to the requirements for strength and ductility and, if appropriate, low temperature performance and hot dip galvanising requirements.

10.10 Characteristics and dimensions of insulators

The characteristics and dimensions of insulators used for overhead line construction shall wherever possible comply with the dimensional requirements of the following EN and IEC Publications:

— string insulator units	— EN 60305 and EN 60433;
— line post insulators	— IEC 60720;
— composite insulators	— EN 61466-1 and EN 61466-2.

NOTE 1 Compliance with the above Publications also requires compliance with HD 474, IEC 60372 and IEC 60471.

NOTE 2 Approved types of insulators with dimensional characteristics differing from those specified in the above standards may be included in the Project Specification. Characteristics, other than dimensional, and tests should comply with the relevant standards.

10.11 Type test requirements

10.11.1 Standard type tests

When required type tests on string insulator units and on line post insulators of ceramic material or glass shall be carried out in accordance with EN 60383-1. Unless otherwise specified in the Project Specification or agreed by the purchaser with the supplier the acceptance criteria for the electrical, mechanical and other characteristics shall be as given in EN 60383-1.

Design and type tests on composite insulators shall be carried out in accordance with IEC 61109. Unless otherwise specified in the Project Specification or agreed by the purchaser with the supplier the acceptance criteria for all characteristics shall be as given in IEC 61109.

Type tests on insulator strings and sets shall be carried out in accordance with EN 60383-2. The acceptance criteria shall be as given in EN 60383-2.

10.11.2 Optional type tests

When specified in the Project Specification or by agreement between the purchaser and supplier additional type tests can be carried out. Suitable standard specifications exist to cover:

— radio interference test	— EN 60437, CISPR 16-2 and CISPR 18-2;
— pollution performance test	— EN 60507;
— power arc performance test	— IEC 61467;
— impulse voltage puncture test	— IEC 61211;
— zinc sleeve test	— EN 61325;
— residual strength test	— IEC 60797.

The performance requirements shall be specified in the Project Specification or agreed by the purchaser with the supplier before the commencement of each test.

If other type tests which are not included in existing national or international standards are required by the purchaser, the details of the test procedures and the acceptance criteria shall be specified in the Project Specification or agreed with the supplier at the time of placing the order.

10.12 Sample test requirements

The specified sample tests shall be carried out on samples taken at random from each lot of insulators offered for delivery. The tests shall be in accordance with the relevant standard for

— string insulator units and line post insulators of ceramic material or glass EN 60383-1,
— composite insulators - IEC 61109.

Unless otherwise specified in the Project Specification or agreed by the purchaser with the supplier at the time of placing the order, the acceptance criteria for all characteristics shall be as given in EN 60383-1 or IEC 61109 as appropriate.

When specified in the Project Specification or agreed by the purchaser with the supplier, other sample tests can be carried out. Examples of these tests are:

— radio interference test on single string insulator units of the cap and pin type – EN 60437;
— zinc sleeve test, where applicable, on pins from cap and pin insulator units – EN 61325.

10.13 Routine test requirements

Routine tests as specified in the relevant standard shall be carried out by the supplier on every unit in a lot offered for delivery. The tests shall be in accordance with the relevant standard:

- string insulator units and line post insulators of ceramic or glass - EN 60383-1;
- composite insulators - IEC 61109.

If conditions of service require any alternative routine tests then the details shall be specified in the Project Specification or agreed by the purchaser with the supplier at the time of placing the order.

10.14 Summary of test requirements

The type, sample and routine test requirements on insulators of ceramic material or glass are summarised in annex P.

Annex P does not include composite insulators. The tests applicable to composite insulators are fully detailed in IEC 61109.

10.15 Test reports and certificates

The results of all type tests shall be reported in certificates issued by the supplier or a qualified organisation. These shall be valid with the conditions and for the periods specified in EN 60383-1, EN 60383-2 or IEC 61109 as appropriate.

The results of sample tests shall be reported in a certificate issued by the supplier for each lot delivered.

The supplier shall certify that all units in each lot delivered have passed the specified routine tests.

Any other requirements for certification shall be specified by the purchaser in the Project Specification.

10.16 Selection, delivery and installation of insulators

Information relating to the selection, delivery and installation of insulators is given in annex Q.

11 Line equipment – Overhead line fittings

11.1 General

Overhead line fittings shall be designed, manufactured and erected in such a way as to meet the overall requirements for the operation, maintenance and environmental impact as determined by the design parameters of the line on the basis of information contained elsewhere in this standard. Design life may be subject to agreement between the supplier and the purchaser.

Overhead line fittings shall be tested in accordance with the requirements of EN 61284, EN 61854 and/or EN 61897. Any alternative or additional parameters shall be defined in the Project Specification.

11.2 Electrical requirements

11.2.1 Requirements applicable to all fittings

The design of all fittings shall be such that they are compatible with the specified electrical requirements (see 5.3) for the overhead line. Grading rings or similar devices shall be used where necessary to reduce the electric field intensity at the line end of insulator sets, including the compression terminations of composite insulators

11.2.2 Requirements applicable to current carrying fittings

Conductor fittings intended to carry the operating current of the conductor shall not, when subjected to the maximum continuous current in the conductor or to short circuit currents, exhibit corresponding temperature rises greater than those of the associated conductor. Also the voltage drop across current carrying conductor fittings shall not be greater than the voltage drop across an equivalent length of conductor.

The methods of test and the acceptance criteria shall be in accordance with EN 61284.

11.3 RIV requirements and corona extinction voltage

Fittings, including spacers and vibration dampers, for overhead lines shall be designed such that under test conditions the levels of radio interference are consistent with the overall level specified for the installation. The visible corona extinction voltage shall, when applicable, be specified in the Project Specification. Further information on corona effect, including radio interference, is given in 5.5 and the method of test is specified in EN 61284.

11.4 Magnetic characteristics

The choice of materials and/or the design of fittings attached to the conductor shall, where appropriate, be such that magnetic losses are acceptably low. The method of test and the acceptance criteria shall, unless otherwise specified in the Project Specification, be in accordance with EN 61284.

11.5 Short circuit current and power arc requirements

Fittings shall, when required, comply with the specified short circuit current or power arc requirements. In particular insulator set fittings shall be such that if a short circuit current or power arc test is required they retain, unless otherwise specified in the Project Specification, at least 80 % of their specified mechanical failing load on completion of the test.

Arcing horns shall be capable of safely carrying the anticipated fault level current for the anticipated duration of the fault without adverse effect on the safety aspects of overhead line maintenance.

Power arc tests on fittings shall be carried out in conjunction with insulator tests (see 10.5) but when agreed between the purchaser and supplier short circuit current follow through tests may be carried out on assemblies of fittings only.

11.6 Mechanical requirements

The design of overhead line fittings shall be such that the specified mechanical design requirements are achieved. The partial factor applied to the specified minimum failure load as defined in EN 61284 for all types of line fittings shall have a minimum value of:

$$\boxed{\gamma_M = 1{,}6}$$

when the Empirical approach to the loading method (see clause 3) is used for actions.

When the General approach to the loading method is used the partial factor applied to the specified minimum failure load shall have a minimum value of:

$$\boxed{\gamma_M = 1{,}6}$$

A higher value of the partial factor may be specified in the Project Specification.

For all fittings where a man may stand the fittings shall withstand a concentrated characteristic load of 1,5 kN.

11.7 Durability requirements

All materials used in the construction of overhead line fittings shall be inherently resistant to atmospheric corrosion which may affect their performance. The choice of materials and/or the design of fittings shall be such that bimetallic corrosion of fittings or conductor is minimised.

All ferrous materials, other than stainless steels, used in the construction of fittings shall be protected against atmospheric corrosion by hot dip galvanising or other methods specified in the Project Specification or agreed by the purchaser with the supplier.

NOTE Reference may also be made to EN ISO 1461.

Fittings subjected to articulation or wear shall be designed, including material selection, and manufactured to ensure maximum wear resistant properties.

11.8 Material selection and specification

Materials used in the manufacture of overhead line fittings shall be selected having regard to their relevant characteristics. The manufacturer shall ensure that the specification and quality control of materials is sufficient to ensure continuous achievement of the specified characteristics and performance requirements.

Locking devices used in the assembly of fittings with socket connectors shall comply with the requirements of IEC 60372.

NOTE When selecting metals or alloys for line fittings the possible effects of low temperature should, where relevant, be considered. When selecting non-metallic materials their possible reaction to temperature extremes, UV radiation, ozone and atmospheric pollution should be considered.

11.9 Characteristics and dimensions of fittings

The mechanical characteristics of insulator set fittings shall comply with the mechanical strength requirements, where appropriate, of EN 60305 and EN 60433 or EN 61466-1.

The coupling dimensions of insulator set fittings shall comply with HD 474 or IEC 60471.

11.10 Type test requirements

11.10.1 Standard type tests

When required type tests on overhead line fittings shall be carried out in accordance with the requirements of EN 61284, EN 61854 and/or EN 61897. Unless otherwise specified by the purchaser in the Project Specification, the acceptance criteria for mechanical and other characteristics shall be as given in these standards..

11.10.2 Optional type tests

When specified in the Project Specification or by agreement between the purchaser and supplier, tests may be carried out to confirm the performance of insulator set fittings under power arc conditions. Information relating to such tests is given in IEC 61467.

11.11 Sample test requirements

The specified sample tests shall be carried out on samples taken at random from each lot of fittings offered for delivery. The tests shall be carried out in accordance with the requirements of EN 61284, EN 61854 and/or EN 61897. Unless otherwise specified in the Project Specification or agreed by the purchaser with the supplier at the time of placing the order the acceptance criteria for all characteristics shall be as given in these standards.

11.12 Routine test requirements

Routine tests as specified in the relevant standard shall be carried out by the supplier on every fitting in a lot offered for delivery. The tests shall be in accordance with the requirements of EN 61284, EN 61854 and/or EN 61897.

NOTE EN 61284, EN 61854 and EN 61897 include examples of non-destructive tests. The extent to which these tests are selected and applied should be agreed between the manufacturer and purchaser and included in the Project Specification.

11.13 Test reports and certificates

The results of all type tests shall be reported in certificates issued by the supplier or a qualified organisation. These shall be valid without time limit provided that there is no change in the design or material of the fitting.

The results of sample tests shall be reported in a certificate issued by the supplier for each lot delivered.

The supplier shall certify that all fittings in each lot delivered have passed the specified routine tests.

11.14 Selection, delivery and installation of fittings

Information relating to the selection, delivery and installation of fittings is given in annex R.

12 Quality assurance, checks and taking-over

12.1 Quality assurance

During the design, manufacture and construction the quality assurance arrangements shall conform to the relevant requirements of EN 9001, EN 9002 and EN 9003 as appropriate.

The systems and procedures, which the designer and/or installation contractor will use to ensure that the project works comply with the project requirements, shall be defined in the designer's and/or installation contractor's quality plan for the project works.

Each quality plan shall set out activities in a logical sequence and shall take into account the following :

— an outline of the proposed work and programme sequence.

— the structure of the organisation for the contract, both at the head office and at any other centres responsible for part of the work.

— the duties and responsibilities assigned to staff ensuring quality of the work.

— hold and notification points.

— submission of engineering documents required by the project specification.

— the inspection of materials and components on receipt.

— reference to the quality assurance procedures appropriate to each activity.

— inspection during manufacture/construction.

— final inspection and testing.

The quality assurance plan is part of the execution plan of a project or a project phase.

12.2 Checks and taking-over

Prior to taking over a new overhead line from a Contractor a number of appropriate measures and checks on the line should be specified before it will be put into service.

It is up to the Engineer in Charge to define in agreement with the Purchaser the exact measures to be taken, by whom it will be done and in which way it will be reported and/or documented.

It is recommended to check the complete line, section by section, component by component, and in the different construction steps, for instance the foundations and stub installation before starting the tower erection, and so on.

A standard format with checklists can usefully help the documentation of the various stages of construction of the line and/or the final state of the line. This format can be established on the basis of the requirements of the general specifications. It allows the comparison of the inspection results of different inspectors on different line components of the same type.

It should be specified that the Contractor will guarantee the conformity of the construction of the overhead line to the general and special specifications as well as to the design drawings by appropriate quality assurance checks.

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Annex A
(informative)

Strength coordination

A.1 Recommended design criteria

In order to decide on an appropriate strength coordination, the following criteria are recommended:

a) the component with lowest level of reliability should be chosen so as to introduce the least secondary load effect (dynamic or static) on other components, in order to minimise cascading failure;

b) repair time and costs following a failure should be kept to a minimum;

c) the component with the lowest reliability ideally has a ratio of the damage limit to the failure limit close to 1,0;

NOTE It may be difficult to coordinate the strength of components when the least reliable one has a very large strength dispersion.

d) a low cost component in series with a high cost component should be designed to be at least as strong and reliable as the major component if the consequences of failure are as severe as for the failure of that major component. An exception to this criterion is when a component is purposely designed to act as a load limiting device. In such a case its strength should be well tuned with the component it is intended to protect.

If line components such as suspension supports, tension supports, conductors, foundations and hardware are analysed using the above criteria, it is found that conductors should not be the weakest component because of a, b and c; hardware because of d; tension supports because of a and b; and foundations because of b and c.

A.2 Proposed strength coordination

An appropriate coordination of strength applying the criteria recommended in A.1 above is given in Table A.1.

It appears from Table A.1 that suspension supports are the component with the lowest reliability and would fail first when the line is subjected to loads exceeding design values.

Table A.1 - Typical coordination of strength

	Major component	Coordination within major components*
To fail first	Suspension support	Support, foundations, hardware
Not to fail first with 90 % confidence	Tension support Section support Dead-end support	Support, foundations, hardware
	Conductors	Conductors, insulators, hardware
NOTE The above strength coordination can be applied to most overhead lines. However, there will be some situations where different criteria can be used and thus lead to another sequence of failure.		
* Within each major component the underlined component is the weakest at the 90 % confidence level.		

In order to develop factors for multiplication of the partial factors as stated in this standard, leading to the target strength coordination, two methods can be considered:

— for the component with the lowest target reliability, design loads should be used in conjunction with the partial factors for actions given in this standard. The next components with higher target reliabilities should then be designed with a lower exclusion limit (percentage factor 5-10 lower), corresponding to the same design values of actions.

— partial factors for material properties should be established in such a way that the target strength coordination between two components will be reached with a high level of confidence (approx. 80 % to 90 %).

NOTE Due to the random distribution of material properties, it is theoretically impossible to guarantee with 100 % confidence level that the sequence of failure will be met in all cases.

Annex B
(informative)

Extreme wind speeds and ice loads

B.1 Definition of symbols used in this annex

Symbol	Signification
B_I	Reduction factor of the extreme wind speed associated with combined ice
I_B	Basic ice load per unit length
I_H	High probability ice load (moderate ice load)
I_L	Low probability ice load (extreme ice load)
I_R	Reference ice load
I_T	Extreme ice load with return period T years
I_m	Maximum yearly ice load
I_{max}	Maximum ice load observed over several years
I_{mm}	Mean value of maximum yearly ice loads
I_{50}	Extreme ice load with return period 50 years
n	Number of years
V	Wind speed, measured values
V_{IH}	High probability wind speed associated with icing (moderate wind speed)
V_{IL}	Low probability wind speed associated with icing (high wind speed)
V_T	Extreme wind speed with return period T years; calculated using Gumbel II, taking into account the relevant return period.
V_m	Maximum yearly wind speed; it is the extreme value of the wind speed V measured during one year, selected from measured values
V_{mm}	Mean value of maximum yearly wind speed; it is the calculated mean value of a series of maximum yearly wind speeds, used as part of statistical analysis
V_{50}	Extreme wind speed with return period 50 years
v_I	Coefficient of variation for maximum yearly ice loads
v_V	Coefficient of variation of maximum yearly wind speed

B.2 Evaluation of extreme wind speed data

The coefficient of variation v_V of maximum yearly wind speed V_m is the calculated standard deviation of a series of maximum yearly wind speeds divided by the mean value V_{mm} of the maximum yearly wind speed.

The extreme wind speed V_T with return period T corresponds to the reliability level selected for the overhead line (see 3.2.2). A suitable distribution should be used to calculate V_T from V_{mm} and v_V. In this standard the Gumbel function is used for this purpose.

The extreme wind speed is usually given with a return period of T = 50 years. In Table B.1 conversion factors are given for obtaining wind speeds with other return periods. Return period T = 3 years should be used for calculating moderate wind speed V_{IH} (with a high probability of occurrence) as defined in B.6.1.

The values in the table are based on a maximum yearly wind speed coefficient of variation of 0,12 and an observation period of 30 years. Conversion factors for other values of coefficient of variation and other lengths of the observation period are found in annex D "Statistical data for Gumbel distribution for extremes" (informative).

The conversion factors $(V_T/V_{50})^2$ for wind pressure (proportional to the square of the wind speed) stated in Table B.1 represent the theoretical value of the partial factor for wind action, γ_W, and in the case of a three year return period the combination factor for wind action, Ψ_W, provided that no other corrections are made.

Table B.1 - Conversion factors for different return periods of wind speed

Return period T Years	Extreme ratio V_T/V_{mm}	Conversion factor V_T/V_{50}	Conversion factor $(V_T/V_{50})^2$
3	1,04	0,76	0,58
50	1,36	1,00	1,00
150	1,48	1,09	1,18
500	1,61	1,18	1,40

NOTE In addition to the statistical data based on measurements, experience from similar sites can be useful in determining the extreme wind speed at the site.

B.3 Definition of extreme ice load

Extreme ice load I_T is equal to the ice load with a return period T which corresponds to the reliability level which is chosen for the overhead line.

The extreme ice load can be calculated according to the Gumbel distribution for extremes based on the mean value I_{mm}, the coefficient of variation v_I for maximum yearly ice loads (see B.4.4 and B.4.5) and the number of years with annual maximum values, n. When $n < 10$, n is set equal to 10.

Table B.2 gives factors to transform these to other return periods. For this transformation $v_I = 0,7$ and $n = 10$ years are used. Return period $T = 3$ years should be used for calculating moderate ice load I_H (with a high probability of occurrence) as defined in B.6.2.

Table B.2 - Conversion factors for different return periods for ice load

Return period T Years	Extreme ratio I_T/I_{mm}	Conversion factor I_T/I_{50}
3	1,30	0,37
50	3,51	1,00
150	4,33	1,23
500	5,22	1,49

The reference ice load I_R is equal to the extreme ice load I_T with possible corrections for local conditions, type of conductor and span length.

The conversion factors in Table B.2 represent the theoretical value of the partial factor for ice action, γ_I, and in the case of a three year return period the combination factor for ice action, Ψ_I, provided that no other corrections are made.

In cases where there are many winters without icing events being observed, other distributions of extremes should be used.

B.4 Statistical ice parameters

B.4.1 Basic ice load

The basic ice load per unit length, I_B, (in N/m) is referred to a conductor of diameter 30 mm in a 100 m long span 10 m above ground on a site which is representative for the overhead line. When measurements are performed on conductors with other diameters or span lengths, they should be transferred according to separate specifications.

B.4.2 Maximum yearly ice load Im

This is the maximum of the ice load I_B in one year.

B.4.3 Maximum ice load over several years Imax

This is the highest ice load observed over a period of several years, if such information exists (see B.4.2).

B.4.4 Mean value Imm of maximum yearly ice loads

This is a calculated or estimated mean value of maximum yearly ice loads (see B.4.2).

B.4.5 Coefficient of variation vI for maximum yearly ice loads

This is a calculated, modified or estimated coefficient of variation for maximum yearly ice loads (see B.4.2).

B.5 Extreme ice load evaluation based on various data sources

B.5.1 Data sources for statistical evaluation

The database available for evaluating ice loads varies widely. This standard describes statistical methods based on three types of data:

— maximum yearly ice load I_m (see B.4.2) recorded for a period of at least 10 years (see B.5.2);

— only the maximum value I_{max} (see B.4.3) for ice load over a limited number of years is recorded (i.e. no statistical data) (see B.5.3);

— maximum yearly ice load calculated by means of meteorological data analyses (icing model) (see B.5.4).

NOTE Use of data on ice loads collected for only a few years may be misleading if the icing seasons were not representative. If possible, a meteorological evaluation should be performed covering a perlod of at least 20-30 years for the area. Unless this is done, misleading conclusions can be drawn from too short periods or non representative seasons.

B.5.2 Yearly maxima ice loads during periods of at least 10 years are available

If the calculated coefficient of variation v_I is outside the range given in Table B.3, it should be set equal to the nearest limit value.

Table B.3 – Coefficient of variations

Number of years of observations n	Mean value I_{mm}	Coefficient of variation v_I
$10 \leq n \leq 20$	I_{mm}	$0,5 \leq v_I \leq 0,7$
$20 < n$	I_{mm}	$v_I \leq 0,7$

B.5.3 Maximum ice load Imax is known only for a limited number of years

The mean value I_{mm} is set equal to 0,4 I_{max}, and the coefficient of variation v_I is set equal to 0,7. Extreme ice load according to B.3 above should be calculated with n = 10 years. (See also note in B.5.1 above).

B.5.4 Evaluation of annual maximum ice load by means of analyses of meteorological data

Values of ice load data for the use of the statistical methods in this standard can be established by means of an icing model. The result from such a model should be used in order to find the mean value I_{mm} and coefficient of variation v_I (see B.4.2, B.4.4 and B.4.5).

An icing model of this type should analyse meteorological data over a period of 20 years or more. In addition to standard meteorological observation parameters, data which are not included in standard weather observations (liquid water content, droplet sizes, precipitation intensities, etc.) are required.

If data which is representative for the location of the overhead line does not exist, a measuring programme can be set up, either to measure the parameters or to measure ice loads directly. In the latter case these should be made with supplementary meteorological measurements and data collected.

A correct calibration of an icing model requires at least 5-10 well-documented icing events. In many locations there can be several seasons without icing events. The time series for meteorological measurements should be performed for at least two seasons, but preferably for 5 years or more. When a new overhead line is planned in an area where little information about icing exists or the line traverses an especially exposed terrain, a possible measurement programme should be considered as early as possible.

B.6 Combination of wind speeds and ice loads

B.6.1 Extreme ice load IL combined with a moderate wind speed VIH

The extreme ice load I_L is equal to I_R defined in B.3 above or is found as $I_L = \gamma_I I_{50}$.

Associated with icing, the moderate wind speed V_{IH} with a return period of T = 3 years is determined as given in B.2 and is further multiplied with a reduction factor B_I, or is found as $V_{IH} = V_{50}\sqrt{\Psi_W}$ where Ψ_W includes the effect of the reduction factor B_I. The factor B_I depends on the type of ice. For wet snow B_I is equal to 0,7 and for in-cloud icing 0,85.

B.6.2 High wind speed VIL combined with moderate ice load IH

Associated with icing, the high wind speed V_{IL} is determined as the extreme wind speed V_T with return period T years given in B.2, or is found as $V_{IL} = V_{50}\sqrt{\gamma_W}$, and is further multiplied by the reduction factor B_I given in B.6.1 above.

The moderate ice load I_H is determined as given in B.3 above, or is found as $I_H = \Psi_I I_{50}$.

NOTE 1 A further simplification can be made by countries which have experience that one or two of the above mentioned combinations are never critical. In some countries it can also be necessary to investigate the possibility of moderate wind speed V_{IH} and moderate ice load I_H combined with extreme values of the drag factor and low ice densities.

NOTE 2 The design approach which uses a three year return period load for the meteorological parameter associated with the extreme one presupposes that the ice and wind phenomena are occurring independently. If available statistics show otherwise in a given region, modified combination factors based on statistics, should be used even if they are lower than specified.

Annex C
(informative)

Special forces

C.1 Definition of symbols used in this annex

Symbol	Signification
$I_{SC2\phi}$	**2 phase short circuit current**
$I_{SC3\phi}$	**3 phase short circuit current**

C.2 Forces due to short circuit currents

The main concern is with swinging of conductors which results in unwanted contacts, the result being a permanent switching off if the circuit-breaker reclosing takes place at that time. Short-circuit conditions may also cause mechanical problems (on supports), but these are less important than those due to conductor swinging.

A possible solution to the swinging problem lies in the use of interphase spacers which reduce the movements by holding the conductors apart from each other (suppressing the conductor whipping). The calculation requires software capable of simulating the forces and movements of conductors during and after the short-circuit.

A mechanical analysis of overhead lines under short-circuit loads may be performed if required by the Project Specification. The following should be considered.

— A short-circuit level should be specified with reference to the levels specified for switchgear rating.

  For information, the short circuit level (short circuit 3 phase current, $I_{SC3\phi}$) in a substation may exceed the following specified levels:

  1) 40 kA for 420 kV highest system voltage;
  2) 31,5 kA for 245 kV highest system voltage;
  3) 20 kA for lower voltages.

— The short-circuit current used for checking is the maximum level allowed by substation equipment (even if it is not attained in the present stage of development of the transmission system) in order to facilitate further evolution of the system.

— The supports close to the substation should be checked taking into account the reduction of the short-circuit current due to line impedance.

— The support check ceases where the short-circuit current decreases to less than the above specified levels.
  This rule should be applied to check 5 to 10 spans from to the substation. Usually, only 1 span is affected by excessive swinging and 1 or 2 supports adjacent to the substation are subjected to mechanical overloads from short circuits.

— Only the 2-phase short circuit current, $I_{SC2\phi}$, should be checked as the most restrictive. As an approximation

$$I_{SC2\phi} = \frac{\sqrt{3}}{2} I_{SC3\phi}$$

The reduction of short-circuit current with time should also be taken into account according to the electrical characteristics of the system. The fault time should be considered in accordance with the type of protection relays used and the possibility of covering breaker failure or not (breaker tripping time without failure estimated at 80 to 200 ms usually with solid state relaying).

C.3 Avalanches, creeping snow

In addition to the effects of direct avalanches, the effects of avalanches from the opposite slope of the valley on overhead lines should not be neglected. This can influence conductors and fittings (especially in case of powdery avalanches), supports and foundations. Creeping snow is to be considered with regard to additional loadings on foundations and lower parts of supports (especially bracing members).

Principles of calculation of loadings caused by avalanches or creeping snow cannot be fully defined and should be specified in the NNAs or Project Specification. The coincident temperature with avalanches may be in the range from – 20 ° to + 10 °C.

Appropriate loading assumptions may help to reduce the risk of failures of supports: for example, in the event of rupture of all conductors and ground wires on one side of the support, the tensions of conductors and ground wires on the remaining side should be taken equal to their breaking strengths.

Values for pressure of creeping snow on protection devices can be found in the Project Specification. Protection measures should be taken with regard to neighbouring buildings as well as to structures on the opposite slope of the same valley which can be influenced by deviated avalanches or snow.

C.4 Earthquakes

Since wind loadings are usually the more determining factor on lattice type overhead line towers, seismic loads which may lead to additional loading forces may be expected only in very active seismic zones. These considerations may include the natural period of vibration of the structure, the site-structure resonance factor (depending on the soil conditions), and the height, weight and mass distribution of the support structure.

Since the frequency of the support is higher than that of conductors, the dynamic load from conductors obviously is not significant. Vice versa no important effects from the support on conductors should be expected.

Ground acceleration due to earthquakes may influence the design of rigid and heavy concrete structures. Effects on the equipment (fittings, insulators, etc.) due to earthquakes are not considered in this annex.

Annex D
(informative)

Statistical data for the Gumbel distribution of extremes

D.1 Definition of symbols used in this annex

Symbol	Signification
C_1, C_2	Parameters depending on the length of the measuring series
G	Complementary probability, or the risk of the extreme value x_i exceeding the chosen value x an arbitrary year
G_1	Gumbel cumulative distribution for extremes
i	Symbol to indicate arbitrary year in a series
K	Factor dependent on the return period T, number of years n and coefficient of variation v
K_{conv}	Conversion factor for different return periods
n	Number of years
v	Coefficient of variation
x_i	Extreme value for a variable x in an arbitrary year
$\overline{x}$	Mean value of a variable x
z_i	Constant calculated for an arbitrary year i in a series of n years
$\overline{z}$	Mean value of z_i and equal to C_2
σ_z	Standard deviation of z_i and equal to C_1
y, α, μ, σ	Factors used in the calculation of Gumbel distribution

D.2 The Gumbel distribution

Although there are several functions which represent extreme distributions, this annex is based on the Gumbel distribution (Fisher-Tipett or Gumbel, type II).

The cumulative distribution can be written

$$G_1(x) = e^{-e^{-y(x)}} \qquad \text{(D.1)}$$

which gives the probability that the extreme value x_i for an arbitrary year is less than any chosen value x. In this equation

$$y = \alpha(x - \mu) \qquad \text{(D.2)}$$

$$\alpha = \frac{C_1}{\sigma} \qquad \text{(D.3)}$$

$$\mu = \overline{x} - \frac{C_2}{\alpha} \qquad \text{(D.4)}$$

where $\overline{x}$ is the mean value of n yearly extremes x_i and σ the standard deviation or the square root of the variance

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad \text{(D.5)}$$

$$\sigma^2 = \frac{1}{n}\sum_{i=1}^{n} (x_i - \overline{x})^2 \qquad \text{(D.6)}$$

$$v = \frac{\sigma}{\overline{x}} \qquad \text{(D.7)}$$

Rather than the standard deviation itself, the per unit value v is more useful in the following. This is also called coefficient of variation.

C_1 and C_2 in equations (D.3) and (D.4) are parameters depending on the length of the measuring series as given by n. They are given in Table D.1.

The complementary probability, or the risk of the extreme value x_i exceeding the chosen value x an arbitrary year is:

$$G(x) = 1 - G_1(x) \qquad \text{(D.8)}$$

The return period T is the inverse value of $G(x)$, here written as $T(x)$ to underline its dependence on the chosen value x:

$$T(x) = \frac{1}{G(x)} \qquad \text{(D.9)}$$

Table D.1 - Values of parameters C_1 and C_2

Length of measuring series ***n***	**Parameters**	
Years	C_1	C_2
10	0,949 6	0,495 2
11	0,967 6	0,499 6
12	0,983 3	0,503 5
13	0,997 1	0,507 0
14	1,009 5	0,510 0
15	1,020 6	0,512 8
16	1,030 6	0,515 4
17	1,039 7	0,517 7
18	1,048 1	0,519 8
19	1,055 7	0,521 7
20	1,062 8	0,523 6
21	1,069 4	0,525 2
22	1,075 5	0,526 8
23	1,081 2	0,528 2
24	1,086 5	0,529 6
25	1,091 4	0,530 9
26	1,096 1	0,532 1
27	1,100 5	0,533 2
28	1,104 7	0,534 3
29	1,108 6	0,535 3
30	1,112 4	0,536 2
35	1,128 5	0,540 3
40	1,141 3	0,543 6
45	1,151 8	0,546 3
50	1,160 7	0,548 5
55	1,168 2	0,550 4
60	1,174 7	0,552 1
65	1,180 3	0,553 5
70	1,185 4	0,554 8
75	1,189 8	0,555 9
80	1,193 8	0,556 9
85	1,197 4	0,557 8
90	1,200 7	0,558 6
95	1,203 7	0,559 3
100	1,206 5	0,560 0
250	1,242 9	0,568 8
500	1,258 8	0,572 4
750	1,265 2	0,573 8
1 000	1,268 5	0,574 5
10 000	1,280 3	0,576 8
∞	1,282 5	0,577 2

Combining equations (D.1), (D.8) and (D.9) gives

$$\frac{1}{T} = 1 - e^{-e^{-y}} \tag{D.10}$$

or

$$y = -\ln(-\ln(1 - \frac{1}{T})) \tag{D.11}$$

It is seen that there is a unique connection between the return period T and the parameter y independent of $\overline{x}$ and σ. This is shown in Table D.2.

Table D.2 - Corresponding values of return period *T*, risk of exceedance *G* and parameter *y*

Return period *T* Years	Risk of exceedance G	Parameter y
3	0,333 3	0,902 7
50	0,020 0	3,901 9
150	0,006 7	5,007 3
500	0,002 0	6,213 6

Equation (D.2) can be written:

$$x = \mu + \frac{y}{\alpha} \tag{D.12}$$

and using (D.4) and (D.3)

$$x = \overline{x} - \frac{\sigma}{C_1}(C_2 - y) \tag{D.13}$$

Observing equation (D.7) and rearranging since y is always > C_2:

$$x = \overline{x}(1 + v\frac{y - C_2}{C_1}) \tag{D.14}$$

Equation (D.14) can be written

$$x = K\,\overline{x} \tag{D.15}$$

where K, a function of v, of T (since y is given by T) and of n (since C_1 and C_2 are given by n) is given by:

$$K(T, v, n) = 1 + v\frac{y - C_2}{C_1} \tag{D.16}$$

Table D.3 gives some K values for return periods T (years), periods of measurement n (years) and coefficients of variation v which might be practical.

Very often it is necessary to convert a given climatic quantity with a return period of 50 years to a quantity with 3, 150 or 500 years. Such conversion factors can be calculated using the same formulae as above. Such a factor would be:

$$K_{conv}(T, v, n) = \frac{K(T, v, n)}{K(50, v, n)} \qquad \text{(D.17)}$$

which is also a function of the return period, coefficient of variation and length of measuring series n.

Table D.4 shows conversion factors from extremes with a return period of 50 years to extremes with return periods of 3, 150 and 500 years, depending on the measured values of the coefficient of variation and length of the measured series.

D.3 Example of using C1 and C2

An example of using C_1 and C_2 may be useful. Wind speeds have been measured for a period of 35 years. The mean value of the yearly extremes is found to be 33 m/s and the coefficient of variation v = 0,12. If the return period T = 50 years is chosen, Table D.2 gives y = 3,901 9. Further, Table D.1 gives C_1 = 1,128 5 and C_2 = 0,540 3 for n = 35. Equation (D.14) then gives a design wind speed:

$$x = 33(1 + 0{,}12\frac{3{,}9019 - 0{,}5403}{1{,}1285}) = 44{,}8 \quad \text{(m/s)}$$

The so-called ideal Gumbel distribution with C_1 = 1,282 5 and C_2= 0,577 2 (based on an infinite measuring period) would give:

$$x = 33(1 + 0{,}12\frac{3{,}9019 - 0{,}5772}{1{,}2825}) = 43{,}3 \quad \text{(m/s)}$$

The more realistic distribution gives a design value 3,5% above that given by the "ideal" one.

D.4 Calculation of C_1 and C_2

With a period of measurement of n years, n z-values can be calculated numbered from 1 to n:

$$z_i = -\ln(-\ln\frac{i}{n+1}) \qquad \text{(D.18)}$$

where i takes on values from 1 to n. A mean value of these z's is found

$$\bar{z} = \frac{1}{n}\sum_{i=1}^{n} z_i \qquad \text{(D.19)}$$

Table D.3 - Factors for calculating design values based on the mean values of yearly extremes

Return period *T*	Period of measurements *n*	Coefficient of variation *v*										
Years	Years	0,10	0,12	0,14	0,16	0,18	0,20	0,30	0,40	0,50	0,60	0,70
3	10	1,04	1,05	1,06	1,07	1,08	1,09	1,13	1,17	1,21	1,26	1,30
	15	1,04	1,05	1,05	1,06	1,07	1,08	1,11	1,15	1,19	1,23	1,27
	20	1,04	1,04	1,05	1,06	1,06	1,07	1,11	1,14	1,18	1,21	1,24
	25	1,03	1,04	1,05	1,05	1,06	1,07	1,10	1,14	1,17	1,20	1,23
	30	1,03	1,04	1,05	1,05	1,06	1,07	1,10	1,13	1,16	1,20	1,23
	35	1,03	1,04	1,04	1,05	1,06	1,06	1,10	1,13	1,16	1,19	1,22
	40	1,03	1,04	1,04	1,05	1,06	1,06	1,09	1,13	1,16	1,19	1,22
	∞	1,03	1,03	1,04	1,04	1,05	1,05	1,08	1,10	1,13	1,15	1,18
50	10	1,36	1,43	1,50	1,57	1,65	1,72	2,08	2,43	2,79	3,15	3,51
	15	1,33	1,40	1,46	1,53	1,60	1,66	2,00	2,33	2,66	2,99	3,32
	20	1,32	1,38	1,45	1,51	1,57	1,64	1,95	2,27	2,59	2,91	3,23
	25	1,31	1,37	1,43	1,49	1,56	1,62	1,93	2,24	2,54	2,85	3,16
	30	1,30	1,36	1,42	1,48	1,54	1,61	1,91	2,21	2,51	2,82	3,12
	35	1,30	1,36	1,42	1,48	1,54	1,60	1,89	2,19	2,49	2,79	3,09
	40	1,29	1,35	1,41	1,47	1,53	1,59	1,88	2,18	2,47	2,77	3,06
	∞	1,26	1,31	1,36	1,42	1,47	1,52	1,78	2,04	2,30	2,56	2,82
150	10	1,48	1,57	1,67	1,76	1,86	1,95	2,43	2,90	2,28	3,85	4,33
	15	1,44	1,53	1,62	1,70	1,79	1,88	2,32	2,76	3,20	3,64	4,08
	20	1,42	1,51	1,59	1,67	1,76	1,84	2,27	2,69	3,11	3,53	3,95
	25	1,41	1,49	1,57	1,66	1,74	1,82	2,23	2,64	3,05	3,46	3,87
	30	1,40	1,48	1,56	1,64	1,72	1,80	2,21	2,61	3,01	3,41	3,81
	35	1,40	1,48	1,55	1,63	1,71	1,79	2,19	2,58	2,98	3,38	3,77
	40	1,39	1,47	1,55	1,63	1,70	1,78	2,17	2,56	2,96	3,35	3,74
	∞	1,35	1,42	1,48	1,55	1,62	1,69	2,04	2,38	2,73	3,08	3,42
500	10	1,60	1,72	1,84	1,96	2,08	2,20	2,81	3,41	4,01	4,61	5,22
	15	1,56	1,67	1,78	1,89	2,01	2,12	2,68	3,23	3,79	4,35	4,91
	20	1,54	1,64	1,75	1,86	1,96	2,07	2,61	3,14	3,68	4,21	4,75
	25	1,52	1,62	1,73	1,83	1,94	2,04	2,56	3,08	3,60	4,12	4,64
	30	1,51	1,61	1,71	1,82	1,92	2,02	2,53	3,04	3,55	4,06	4,57
	35	1,50	1,60	1,70	1,80	1,90	2,01	2,51	3,01	3,51	4,02	4,52
	40	1,50	1,60	1,70	1,79	1,89	1,99	2,49	2,99	3,48	3,98	4,48
	∞	1,44	1,53	1,62	1,70	1,79	1,88	2,32	2,76	3,20	3,64	4,08

Table D.4 - Conversion factors for calculating design values based on the corresponding values with 50 years return period

Return period T	Period of measurements *n*	Coefficient of variation *v*										
Years	Years	0,10	0,12	0,14	0,16	0,18	0,20	0,30	0,40	0,50	0,60	0,70
3	10	0,77	0,74	0,71	0,68	0,65	0,63	0,54	0,48	0,43	0,40	0,37
	15	0,78	0,75	0,72	0,69	0,67	0,65	0,56	0,50	0,45	0,41	0,38
	20	0,79	0,75	0,73	0,70	0,68	0,65	0,57	0,50	0,46	0,42	0,39
	25	0,79	0,76	0,73	0,71	0,68	0,66	0,57	0,51	0,46	0,42	0,39
	30	0,79	0,76	0,73	0,71	0,69	0,66	0,58	0,51	0,46	0,43	0,39
	35	0,80	0,77	0,74	0,71	0,69	0,67	0,58	0,51	0,47	0,43	0,40
	40	0,80	0,77	0,74	0,71	0,69	0,67	0,58	0,52	0,47	0,43	0,40
	∞	0,81	0,79	0,76	0,74	0,71	0,69	0,60	0,54	0,49	0,45	0,42
50	All	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
150	10	1,09	1,10	1,11	1,12	1,13	1,14	1,17	1,19	1,21	1,22	1,23
	15	1,08	1,09	1,10	1,11	1,12	1,13	1,16	1,19	1,20	1,22	1,23
	20	1,08	1,09	1,10	1,11	1,12	1,13	1,16	1,18	1,20	1,21	1,23
	25	1,08	1,09	1,10	1,11	1,12	1,13	1,16	1,18	1,20	1,21	1,22
	30	1,08	1,09	1,10	1,11	1,12	1,12	1,16	1,18	1,20	1,21	1,22
	35	1,08	1,09	1,10	1,11	1,11	1,17	1,16	1,18	1,20	1,21	1,22
	40	1,07	1,09	1,10	1,11	1,11	1,12	1,15	1,18	1,20	1,21	1,22
	∞	1,07	1,08	1,09	1,10	1,11	1,11	1,15	1,17	1,19	1,20	1,21
500	10	1,18	1,20	1,23	1,25	1,27	1,28	1,35	1,40	1,44	1,46	1,49
	15	1,17	1,19	1,22	1,24	1,26	1,27	1,34	1,39	1,43	1,45	1,48
	20	1,17	1,19	1,21	1,23	1,25	1,27	1,33	1,38	1,42	1,45	1,47
	25	1,16	1,19	1,21	1,23	1,25	1,26	1,33	1,38	1,42	1,45	1,47
	30	1,16	1,18	1,20	1,22	1,24	1,26	1,33	1,38	1,41	1,44	1,47
	35	1,16	1,18	1,20	1,22	1,24	1,26	1,32	1,37	1,41	1,44	1,46
	40	1,16	1,18	1,20	1,22	1,24	1,26	1,32	1,37	1,41	1,44	1,46
	∞	1,14	1,17	1,19	1,20	1,22	1,24	1,30	1,35	1,39	1,42	1,45

The parameter C_2 is simply equal to this mean value:

$$C_2 = \bar{z} \tag{D.20}$$

The variance of the z_i's is then found:

$$\sigma_z^2 = \frac{1}{n}\sum_{i=1}^{n}(z_i - \bar{z})^2 \tag{D.21}$$

where σ_z is the standard deviation of z_i.The parameter C_1 is simply equal to this standard deviation:

$$C_1 = \sigma_z \tag{D.22}$$

With some rearrangement the variance can be expressed as follows

$$\sigma_z^2 = \frac{1}{n}\sum_{i=1}^{n} z_i^2 - \bar{z}^2 \tag{D.23}$$

This makes calculation easier, since the summation can be carried out before z is known.

An example shows how C_1 and C_2 are calculated for $n = 10$.

Table D.5 - Calculation and summation of z and z^2

i	z	z^2
1	- 0,874 6	0,764 9
2	- 0,533 4	0,284 5
3	- 0,261 8	0,068 5
4	- 0,011 5	0,000 1
5	0,237 7	0,056 5
6	0,500 7	0,250 7
7	0,794 1	0,630 6
8	1,144 3	1,309 4
9	1,606 1	2,579 5
10	2,350 6	5,525 4
Σ	4,952 1	11,470 2

The first sum in Table D.5 gives:

$$\bar{z} = \frac{1}{10}\sum_{i=1}^{10} z_i = 0{,}49521$$

and then successively

$$\sigma_z^2 = \frac{1}{10}\sum_{i=1}^{10} z_i^2 - \bar{z}^2 = 1{,}14702 - 0{,}24523 = 0{,}90179$$

$$\sigma_z = 0{,}9496$$

$$C_1 = \sigma_z = 0{,}9496$$

and

$$C_2 = \bar{z} = 0{,}4952$$

It can be shown that if $n \to \infty$ then $C1 \to \pi/\sqrt{6}$ = 1,282 549 and $C2 \to$ 0,577 216. The latter is called Euler's constant.

Annex E
(normative)

Electrical requirements

E.1 Definition of symbols used in this annex

Symbol	Signification
D_{el}	Minimum air clearance required to prevent a disruptive discharge between conductors and objects at earth potential during fast front or slow front overvoltages
D_{pp}	Minimum air clearance required to prevent a disruptive discharge between phase conductors during fast front or slow front overvoltages
$D_{50Hz\_p\_p}$	Minimum air clearance required to prevent a disruptive discharge at power frequency voltage between phase conductors
$D_{50Hz\_p\_e}$	Minimum air clearance required to prevent a disruptive discharge at power frequency voltage between a phase conductor and objects at earth potential
d	Clearance distance of the gap
d_{is}	Clearance distance between the extremities of the insulator string
K_a	Altitude factor
K_{cs}	Statistical coordination factor
K_g	Gap factor. For each type of voltage stress, the gap factor can be expressed in terms of the switching impulse gap factor
K_{g_ff}	Lightning impulse gap factor of the air gap, expressed in terms of switching impulse gap factor K_g, $K_{g\_ff} = 0{,}74 + 0{,}26\ K_g$
$K_{g\_ff\_is}$	Lightning impulse gap factor of the insulator strings
K_{g_pf}	Power frequency gap factor of the air gap, expressed in terms of switching impulse gap factor K_g, $K_{g\_pf} = 1{,}35\ K_g - 0{,}35\ K_g^2$
K_{g_sf}	Switching impulse gap factor of the air gap
K_z	Deviation factor
K_{z_ff}	Deviation factor of the air gap withstand voltage distribution for fast front overvoltages. $K_{z\_ff} = 0{,}961$
K_{z_pf}	Deviation factor of the air gap withstand voltage distribution for power frequency voltages, $K_{z\_pf} = 0{,}91$
K_{z_sf}	Deviation factor of the air gap withstand voltage distribution for slow front overvoltages, $K_{z\_sf} = 0{,}922$
N	Number of standard deviations corresponding to U_{rw}
P(U)	Discharge probability function
$U_{2\%\_sf}$	2 % slow front overvoltage stressing the air gap (i.e slow front overvoltage having a probability of 2 % of being exceeded)
$U_{e2\%\_sf}$	2 % slow front overvoltage phase to earth
$U_{p2\%\_sf}$	2 % slow front overvoltage phase to phase
$U_{100\%}$	100 % withstand voltage of the air gap
$U_{50\%}$	50 % withstand voltage of the air gap
U_{50rp}	50 % withstand voltage of a rod-plane gap

U_{50rp_sf}	50 % withstand voltage of a rod-plane gap for slow-front overvoltages
U_{50rp_ff}	50 % withstand voltage of a rod plane gap for fast-front overvoltages
U_{50rp_50Hz}	50 % withstand voltage of a rod plane gap for power frequency overvoltages
$U_{90\,\%}$	90 % withstand voltage of the air gap
$U_{90\,\%\_ff\_is}$	90 % lightning withstand voltage of the insulator strings installed on a line
U_{cw}	Co-ordination withstand voltage
U_{rp}	Representative overvoltage
U_{rw}	Required withstand voltage of the air gap
U_s	Highest system voltage (kV rms)
Z	Standard deviation
z	Coefficient of variation $z = Z/U_{50\,\%}$

E.2 Insulation co-ordination

E.2.1 Development of theoretical formulae for calculating electrical distances

The method given in this annex is that used to derive the electrical clearance distances tables containing D_{el}, D_{pp}, $D_{50Hz\_p\_e}$, $D_{50Hz\_p\_p}$ in the insulation co-ordination subclause 5.3. It is based upon the work of ENV 50196 supported by information from EN 60071-1, EN 60071-2 and CIGRÉ Report 72 "Guidelines for the evaluation of the dielectric strength of external insulation".

E.2.2 Required withstand voltage of the air Urw

The ability of self-restoring insulation to withstand dielectric stresses caused by the application of an impulse of given shape can be described in statistical terms. For a given insulation and for impulses of given shape and various peak values voltages, a discharge probability P can be associated with every possible value of the voltage. The function P is normally given by a mathematical function which is fully described by the parameters U50 %, Z and N. EN 60071-2 recommends the use of a modified Weibull distribution function whose parameters are determined in such a way as to correspond to a gaussian function for the 50 % and 16 % probability of flashover and to truncate the distribution at U50 % - 3 Z.

The required withstand voltage of the air gap may then be expressed as a function of the 50 % withstand voltage of the air gap:

$$U_{rw} = U_{90\,\%} = U_{50\,\%} - N\,Z$$

where

$U_{50\,\%}$ is the 50 % withstand voltage of the air gap;

Z is the standard deviation;

N is the number of standard deviations corresponding to U_{rw}.

For the transient stresses (fast front and slow front overvoltages), the required statistical withstand voltage is the 90 % withstand voltage of the air gap. As a function of the 50 % withstand voltage of the air gap it is defined in terms of the following relationship:

$$U_{rw} = U_{90\,\%} = U_{50\,\%} - 1{,}3\,Z$$

For the power frequency voltages, the required withstand voltage considered is deterministic:

$U_{rw} = U_{100\,\%} = U_{50\,\%} - 3\,Z$

Deviation factors

The standard deviations can be expressed in terms of the 50 % withstand voltage:

$Z = z \cdot U_{50\,\%}$

The following standard deviations are usually considered:

— for lightning impulses: $z = 0{,}03$ and $Z = 0{,}03\ U50\,\%$;
— for switching impulses: $z = 0{,}06$ and $Z = 0{,}06\ U50\,\%$;
— for power frequency voltages: $z = 0{,}03$ and $Z = 0{,}03\ U50\,\%$.

The effect of atmospheric conditions is taken into account in the above values of conventional deviations.

The required withstand voltage may then be expressed using a deviation factor K_z.

$U_{rw} = K_z \cdot U_{50\,\%}$

The resulting deviation factors K_z are given in Table E.1:

Table E.1 - Deviation factors

Type of voltage stress	Required withstand voltage of the air gap U_{rw}	Standard deviation Z	Deviation Factor K_z
Lightning	$U_{rw} = U_{90\,\%} = U_{50\,\%} - 1{,}3\,Z$	$0{,}03\ U_{50\,\%}$	$K_{z\_ff} = 0{,}961$
Switching	$U_{rw} = U_{90\,\%} = U_{50\,\%} - 1{,}3\,Z$	$0{,}06\ U_{50\,\%}$	$K_{z\_sf} = 0{,}922$
Powerfrequency	$U_{rw} = U_{100\,\%} = U_{50\,\%} - 3\,Z$	$0{,}03\ U_{50\,\%}$	$K_{z\_pf} = 0{,}910$

Gap factors

In general, the configuration of the air gap has an effect on its dielectric strength. For a given configuration, the 50 % withstand voltage of the air gap can be expressed as a function of the 50 % withstand voltage of a rod-plane gap:

$U_{50\,\%} = K_g \cdot U_{50rp}$

where K_g is the gap factor.

For each type of voltage stress, the gap factor can be expressed in terms of the switching impulse gap factor:

— slow front overvoltages : $K_{g\_sf} = K_g$;
— fast front overvoltages : $K_{g\_ff} = 0{,}74 + 0{,}26\,K_g$;
— power frequency voltages : $K_{g\_pf} = 1{,}35\,K_g - 0{,}35\,K_g^2$.

The required withstand voltage may then be expressed using the gap factor K_g.

$$U_{rw} = K_z \cdot K_g \cdot U_{50rp}$$

The values of gap factors to be used for slow front overvoltages depend on the configuration. Four types of configurations are considered in the present standard:

Table E.2 - Gap factors

Nature of air clearance	Configuration	Gap factor for slow front overvoltages $K_{g\_sf} = K_g$
External clearances	conductor-obstacle (safety clearances).	1,30
Internal clearances	conductor-window, e.g. air gap configuration between a conductor inside a tower window and the tower structure. • vertical string or V string inside the window.	1,25
	conductor-structure, e.g. air gap clearance between a conductor, connected to a free swinging insulator string at the extremity of a cross-arm, and the tower structure. • vertical string at the extremity of a cross-arm; • V strings.	1,45
	conductor-conductor.	1,60

The gap factors in Table E.2 are typical values only. In practice, other values supported by experiments may be used. Typical gap factor values can be obtained from EN 60071-2, annex G.

Insulation response to overvoltages

The performance of external insulation can be more precisely determined under experimental conditions for positive polarity rather than negative polarity. Formulae describing the performance of rod-plane gaps in negative polarity exist in the literature, but they have not been sufficiently tested. They also have restricted validity. Consequently, the proposed dimensioning will be made for positive polarity. EN 60071-2 gives formulae describing the response of a rod-plane gap to overvoltages in which the 50 % withstand voltage of the rod plane gap U50rp is given depending on the clearance distance d of the gap:

$$U_{50rp} = f\,(d)$$

Consequently the required withstand voltage of the air gap can be expressed depending on the clearance distance d of the gap:

$$U_{rw} = K_z \cdot K_g \cdot f(d)$$

Slow-front overvoltages

Under slow-front overvoltages, a given self-restoring insulation exhibits an appreciably lower withstand voltage than under fast-front surges of the same polarity. In practice, for rod-plane gaps of up to 25 metres, the positive-polarity for critical peak time is given by:

$$U_{50rp\_sf} = 1\,080 \cdot \ln(0,46\ d + 1) \qquad \text{[kV crest]; d (m)}$$

Fast-front overvoltages

For standard lightning impulses applied to rod-plane gaps of up to 10 metres, the positive polarity breakdown strength is given by:

$$U_{50rp\_ff} = 530\ d \qquad \text{[kV crest]; d (m)}$$

Power frequency voltages

The 50 % breakdown voltage for a rod-plane gap can be approximated to by the following equation :

$$U_{50\,rp\_50\,Hz} = 750 \bullet \sqrt{2} \bullet \ln(1 + 0,55\,d^{1,2}) \quad \text{[kV crest]; d (m)}$$

E.2.3 Overvoltages to be taken into account

Fast front overvoltages caused by lightning shall be considered for the calculation of clearances in systems in Range I and II of EN 60071-1.

Slow front overvoltages caused by switching shall be considered for the calculation of clearances in systems in Range II of EN 60071-1.

According to 5.3.3 the representative overvoltages to be taken into account are as follows:

Fast front overvoltages

For the purpose of determining air clearances the representative overvoltage to be considered is that which can propagate beyond a few towers from the point of the lightning strike. For phase to earth clearances it shall be taken as $U_{90\%\_ff\_is}$ the 90 % lightning withstand voltage of the insulator strings installed on the line. For phase to phase clearances it shall be taken as 1,20 $U_{90\%\_ff\_is}$.

Slow front overvoltages

A simplified statistical method for slow front overvoltages suitable for the insulation co-ordination of overhead lines can be used if it is assumed that the distribution of overvoltage and insulation strength can be defined by a point on each of these curves.

The overvoltage distribution is identified by the statistical overvoltage $U_{2\%\_sf}$, which is the overvoltage having a 2 % probability of being exceeded. The insulation strength is identified by the statistical withstand voltage, which is the voltage at which the insulation exhibits a 90 % probability of withstand. The representative overvoltage U_{rp} is obtained by multiplying the statistical overvoltage by a statistical co-ordination factor K_{cs}:

— phase to earth $K_{cs} \cdot U_{e2\%\_sf}$;

— phase to phase $K_{cs} \cdot U_{p2\%\_sf} = 1{,}4 \cdot K_{cs} \cdot U_{e2\%\_sf}$.

The risk of failure is related to the statistical co-ordination factor K_{cs}. For the purpose of determining electrical clearance distances, K_{cs} may be taken equal to 1,05 which corresponds to a risk of failure of the order of $1{,}0 \times 10^{-3}$.

Power frequency voltages

For purposes of insulation design and co-ordination, the representative continuous voltage should be considered as constant and equal to the highest system voltage:

— phase to earth $\frac{\sqrt{2}}{\sqrt{3}} \cdot U_s$ (peak value);

— phase to phase $\sqrt{2} \cdot U_s$ (peak value).

Table E.3 - Representative overvoltages

	Representative overvoltage U_{rp}	
	Phase to earth	**Phase to phase**
Lightning	$U_{90\%\_ff\_is}$	$1{,}2 \cdot U_{90\%\_ff\_is}$
Switching	$K_{cs} \cdot U_{e2\%\_sf}$	$1{,}4 \cdot K_{cs} \cdot U_{e2\%\_sf}$
Power frequency	$\frac{\sqrt{2} \cdot U_s}{\sqrt{3}}$	$\sqrt{2} \cdot U_s$
$U_{90\%\_ff\_is}$ is the maximum of the 90 % lightning impulse withstand voltages of the insulator strings on the line (*); $U_{e2\%\_sf}$ is the 2 % slow front overvoltage phase to earth stressing the air gap (i.e. slow front overvoltage having a probability of 2 % of being exceeded); U_s is the highest system voltage (kV rms).		

(*) The value $U_{90\%\_ff\_is}$ may not be known by some utilities. In this case $U_{90\%\_ff\_is}$ can be derived from the values of the clearance distance of the insulator strings and of their gap factors.

$$U_{90\%\_ff\_is} = K_{z\_ff} \cdot K_{g\_ff\_is} \cdot 530 \cdot d_{is}$$

where:

K_{z_ff} is the deviation factor (K_z = 0,961);

$K_{g\_ff\_is}$ is the lightning impulse gap factor of the insulator strings;

d_{is} is the clearance distance between the extremities of the insulator string.

E.2.4 Calculation formulae

For each type of voltage stress, the co-ordination withstand voltage of the air gap should be higher than or equal to the representative overvoltage so that the failure rate is acceptable.

Considering the altitude factor to be taken into account for the correction of the co-ordination withstand voltage (see 5.3 and E.2.5) and the formulation of the required withstand voltage given in E.2.2:

$$\begin{cases} U_{cw} \geq U_{rp} \\ U_{rw} = \dfrac{U_{cw}}{K_a} \\ U_{rw} = K_z.K_g.f(d) \end{cases}$$

The formulae given in Table E.5, giving the electrical clearance distances to be used, may be deduced from these expressions.

E.2.5 Altitude factor

The values in 5.3 are obtained for altitudes up to 1 000 metres. The electrical clearance distances of lines designed for a higher altitude or in a country where the altitude is rather low can be corrected using the other altitude factors given in Table E.4.

Table E.4 - Altitude factor K_a depending on the co-ordination withstand voltages considered

	Altitude factor K_a				
Altitude (m)	up to 200 kV	from 201 kV to 400 kV	from 401 kV to 700 kV	from 701 kV to 1 100 kV	above 1 100 kV
0	1,000	1,000	1,000	1,000	1,000
100	0,994	0,995	0,997	0,998	0,999
300	0,982	0,985	0,990	0,993	0,996
500	0,970	0,975	0,982	0,987	0,992
1 000	0,938	0,946	0,959	0,970	0,978
1 500	0,904	0,915	0,934	0,948	0,960
2 000	0,870	0,883	0,906	0,923	0,938
2 500	0,834	0,849	0,875	0,896	0,913
3 000	0,798	0,815	0,844	0,867	0,885
NOTE The K_a values have been taken from the document IEC 61472.					

Table E.5 - Formulae for the calculation of D_{el}, D_{pp}, $D_{50Hz\_p\_e}$, $D_{50Hz\_p\_p}$

	D_{el}	D_{pp}
For fast front overvoltages	$D_{el}=\dfrac{U_{90\%\_ff\_is}}{530\cdot K_a\cdot K_{z\_ff}\cdot K_{g\_ff}}=\dfrac{1}{K_a}\cdot\dfrac{K_{g\_ff\_is}}{K_{g\_ff}}\cdot d_{is}$	$D_{pp}=\dfrac{1{,}2\cdot U_{90\%\_ff\_is}}{530\cdot K_a\cdot K_{z\_ff}\cdot K_{g\_ff}}$

d_{is} is the clearance distance between the extremities of the insulator string;
K_a is the altitude factor according to Table E.4;
K_{g_ff} is the lightning impulse gap factor of the air gap, expressed in terms of switching impulse gap factor K, $K_{g\_ff}=0{,}74+0{,}26\cdot K_g$;
$K_{g\_ff\_is}$ is the lightning impulse gap factor of the insulator string;
K_{z_ff} is the deviation factor of the air gap withstand voltage distribution for fast front overvoltages, $K_{z\_ff} = 0{,}961$;
$U_{90\%\_ff\_is}$ is the maximum of the 90 % lightning impulse withstand voltages of the insulator strings on the line.

	D_{el}	D_{pp}
For slow front overvoltages (mainly above 245 kV)	$D_{el}=\dfrac{1}{0{,}46}\cdot\left(e^{\frac{K_{cs}\cdot U_{e2\%\_sf}}{1080\cdot K_a\cdot K_{z\_sf}\cdot K_{g\_sf}}}-1\right)$	$D_{pp}=\dfrac{1}{0{,}46}\cdot\left(e^{\frac{1{,}4\cdot K_{cs}\cdot U_{e2\%\_sf}}{1080\cdot K_a\cdot K_{z\_sf}\cdot K_{g\_sf}}}-1\right)$

K_a is the altitude factor according to Table E.4;
K_{cs} is the coordination statistical factor;
K_{g_sf} is the switching impulse gap factor of the air gap, $K_{g\_sf}= K_g$, according to Table E.2;
K_{z_sf} is the deviation factor of the air gap withstand voltage distribution for slow front overvoltages, $K_{z\_sf} = 0{,}922$;
$U_{e2\%\_sf}$ is the 2 % slow front overvoltage phase to earth stressing the air gap (i.e. slow front overvoltage having a probability of 2 % of being exceeded).

	$D_{50Hz\_p\_e}$	$D_{50Hz\_p\_p}$
For power frequency overvoltages	$D_{50Hz\_p\_e}=\left[\dfrac{e^{\frac{U_s}{750\cdot\sqrt{3}\cdot K_a\cdot K_{z\_pf}\cdot K_{g\_pf}}}-1}{0{,}55}\right]^{0{,}83}$	$D_{50Hz\_p\_p}=\left[\dfrac{e^{\frac{U_s}{750\cdot K_a\cdot K_{z\_pf}\cdot K_{g\_pf}}}-1}{0{,}55}\right]^{0{,}83}$

e is the number 2,718;
K_a is the altitude factor according to Table E.4;
K_{g_pf} is the power frequency gap factor of the air gap, expressed in terms of switching impulse gap factor K_g, $K_{g\_pf}=1{,}35K_g-0{,}35K_g^2$;
K_{z_pf} is the deviation factor of the air gap withstand voltage distribution for power frequency voltages, $K_{z\_pf} = 0{,}91$;
U_s is the highest system voltage (kV rms).

Annex F
(informative)

Electrical requirements

F.1 Definition of symbols used in this annex

Symbol	Signification
D_{50Hz}	Minimum air clearance required to prevent a disruptive discharge at power frequency voltage
D_{el}	Minimum air clearance required to prevent a disruptive discharge between conductors and objects at earth potential during fast front or slow front overvoltages
D_{pp}	Minimum air clearance required to prevent a disruptive discharge between phase conductors during fast front or slow front overvoltages
K_a	Altitude factor
K_{cs}	Statistical coordination factor
K_{g_sf}	Switching impulse gap factor of the air gap
K_{z_ff}	Deviation factor of the air gap withstand voltage distribution for fast front overvoltages. K_{z_ff} = 0,961
K_{z_pf}	Deviation factor of the air gap withstand voltage distribution for power frequency voltages, K_{z_pf} = 0,91
K_{z_sf}	Deviation factor of the air gap withstand voltage distribution for slow front overvoltages, K_{z_sf} = 0,922
$U_{2\,\%\_sf}$	2 % slow front overvoltage stressing the air gap (i.e. slow front overvoltage having a probability of 2 % of being exceeded)
$U_{90\,\%\_ff\_is}$	90 % lighting withstand voltage of the insulator strings installed on a line
U_s	Highest system voltage

F.2 Insulation coordination. Examples of calculation of Del, Dpp and D50 Hz for different system voltages

F.2.1 Range I: 90 kV system equipped with insulator strings composed of 6 units

The following example illustrates the calculation of the electrical clearance distances for a 90 kV system, equipped with insulator strings composed of 6 units, for lines at a height of 1 000 metres above sea level.

— The highest system voltage is U_s = 100 kV.
— For this system voltage, there is no need to consider any switching overvoltage.
— For the purpose of this example, it is considered that when insulator strings composed of 6 units are used, the value of fast front overvoltage to be taken into account is:

— phase to earth : $U_{90\,\%\_ff\_is}$ = 385 kV.

— According to the above mentioned overvoltages and to Table E.4, the altitude factors to be used at a height of 1 000 metres above sea level are then:

— fast front overvoltages:

phase to earth $K_a = 0{,}946$;
phase to phase $K_a = 0{,}959$.

— power frequency voltage:

phase to earth and phase to phase $K_a = 0{,}938$.

— The deviation factors to be considered are the following:

— fast front overvoltages $K_{z\_ff} = 0{,}961$;
— power frequency voltage $K_{z\_pf} = 0{,}910$.

— For the four air gap configurations taken into account in the present standard, the gap factors (K_{g_sf}) defined in Table E.2, for slow front overvoltages are the following:

— conductor-conductor 1,60;
— conductor-window 1,25;
— conductor-structure 1,45;
— conductor-obstacle 1,30.

— The values of the electrical clearance distances are then calculated using the formulae defined in E.2, Table E.5.

Conductor - window configuration (K_{g_sf} = 1,25):

— for fast front overvoltages

$$D_{el} = \frac{385}{530 \mathrm{x} 0{,}946 \mathrm{x} 0{,}961 \mathrm{x} (0{,}74 + 0{,}26 \mathrm{x} 1{,}25)} = 0{,}75 \text{ m}$$

— for power frequency overvoltages

$$D_{50Hz\_p\_e} = \left(\frac{e^{\frac{100}{750\sqrt{3} \mathrm{x} 0{,}938 \mathrm{x} 0{,}910 \mathrm{x} \left(1{,}35 \mathrm{x} 1{,}25 - 0{,}35 \mathrm{x} 1{,}25^2\right)}} - 1}{0{,}55} \right)^{0{,}83} = 0{,}21 \text{ m}$$

For the conductor-structure and conductor-obstacle configurations, the calculation is the same except for the value of the gap factor. The clearance distances are given in Table F.1.

Conductor - conductor configuration (K_{g_sf} = 1,60):

— for fast front overvoltages

$$D_{pp} = \frac{1{,}2x385}{530x0{,}959x0{,}961x(0{,}74+0{,}26x1{,}60)} = 0{,}82\ m$$

— for power frequency overvoltages

$$D_{50Hz\_p\_p} = \left(\frac{e^{\frac{100}{750x0{,}938x0{,}910x\left(1{,}35x1{,}60-0{,}35x1{,}60^2\right)}} - 1}{0{,}55} \right)^{0{,}83} = 0{,}30\ m$$

Table F.1 - Clearance distances - 90 kV system equipped with insulator strings composed of 6 units

	cd [a]- window (K_{g_sf} = 1,25)	cd [a]- structure (K_{g_sf} = 1,45)	cd [a]- obstacle (K_{g_sf} = 1,30)	cd [a]- cd (K_{g_sf} = 1,60)
D_{el} and D_{pp}	D_{el} = 0,75 m	D_{el} = 0,71 m	D_{el} = 0,74 m	D_{pp} = 0,82 m
D_{50Hz}	$D_{50Hz\_p\_e}$ = 0,21 m	$D_{50Hz\_p\_e}$ = 0,19 m	-	$D_{50Hz\_p\_p}$ = 0,30 m
[a] cd: conductor.				

F.2.2 Range I: 90 kV system equipped with insulator strings composed of 9 units

The following example illustrates the calculation of the electrical clearance distances for a 90 kV system, equipped with insulator strings composed of 9 units, for lines at a height, of 1 000 metres above sea level.

— The highest system voltage is the same as in the previous example. The air clearances necessary to withstand the power frequency voltage are then the same.

— The 90 % withstand voltage for fast front overvoltages of the line insulation is much higher when the insulator strings are composed of 9 units than when they only have 6 units. For the purpose of this example, it is considered that when insulator strings composed of 9 units are used, the value of fast front overvoltage to be taken into account is:

— phase to earth : $U_{90\%\_ff\_is}$ = 557 kV.

— According to the above mentioned overvoltage, the altitude factor to be used at a height of 1 000 metres above sea level is then:

— phase to earth and phase to phase: K_a = 0,959.

— The other factors being the same as in the previous example, the values of the electrical clearance distances are then calculated using the formulae defined in E.2, Table E.5:

Conductor - window configuration (K_{g_sf} = 1,25):

— for fast front overvoltages

$$D_{el} = \frac{557}{530x0,959x0,961x(0,74 + 0,26x1,25)} = 1,07\text{ m}$$

For the conductor-structure and conductor-obstacle configurations, the calculation is the same except for the value of the gap factor. The clearance distances are given in Table F.2.

Conductor - conductor configuration (K_{g_sf} = 1,60):

— for fast front overvoltages

$$D_{pp} = \frac{1,2x557}{530x0,959x0,961x(0,74 + 0,26x1,60)} = 1,18\text{ m}$$

Table F.2 - Clearance distances - 90 kV system equipped with insulator strings composed of 9 units

	cd [a]- window (K_{g_sf} = 1,25)	cd [a]- structure (K_{g_sf} = 1,45)	cd [a]- obstacle (K_{g_sf} = 1,30)	cd [a]- cd (K_{g_sf} = 1,60)
D_{el} and D_{pp}	D_{el} = 1,07 m	D_{el} = 1,02 m	D_{el} = 1,06 m	D_{pp} = 1,18 m
[a)] cd: conductor.				

NOTE The clearances values obtained in these two examples show that for a given nominal voltage, the electrical clearance distances may be very different from one network to another depending on the line insulation. This justifies that Table 5.2 gives a clearance value for each standard lighting impulse withstand voltage. Care should then be taken using Table 5.5 which gives a unique typical clearance value depending on the system voltage.

F.2.3 Range II : 400 kV system

The following example illustrates the calculation of the electrical clearance distances for a 400 kV system at a height of 1 000 metres above sea level.

— The highest system voltage is U_s = 420 kV.

— For the purpose of this example, it is considered that when insulator strings composed of 19 units are used, the value of fast front overvoltage to be taken into account is:

— phase to earth : $U_{90\%\_ff\_is}$ = 1 550 kV.

— For the purpose of this example, it is considered that the value of slow front overvoltage to be taken into account is:

— phase to earth : $K_{cs} \cdot U_{2\%\_sf}$ = 1,05 x 1 050 = 1 103 kV;

— phase to phase : $1,40 \cdot K_{cs} \cdot U_{2\%\_sf}$ = 1,40 x 1,05 x 1 050 = 1 544 kV.

— According to the above mentioned overvoltage, the altitude factors to be used at a height of 1 000 metres above sea level are then:

— slow and fast front overvoltages:
phase to earth and phase to phase $K_a = 0{,}978$.

— Power frequency voltage:
phase to earth $K_a = 0{,}946$;
phase to phase $K_a = 0{,}959$.

— The deviation factors to be considered are the following:
— fast front overvoltages $K_{z\_ff} = 0{,}961$;
— slow front overvoltages $K_{z\_sf} = 0{,}922$;
— power frequency voltage $K_{z\_pf} = 0{,}910$.

— The values of the electrical clearance distances are then calculated using the formulae defined in E.2, Table E.5:

Conductor - window configuration ($K_{g\_sf} = 1{,}25$) :

— for fast front overvoltages

$$D_{el} = \frac{1550}{530x0{,}978x0{,}961x(0{,}74 + 0{,}26x1{,}25)} = 2{,}92\ m$$

— for slow front overvoltages

$$D_{el} = \frac{1}{0{,}46}\cdot\left(e^{\frac{1{,}05x1050}{1080x0{,}978x0{,}922x1{,}25}} - 1\right) = 3{,}20\ m$$

— for power frequency overvoltages

$$D_{50Hz\_p\_e} = \left(\frac{e^{\frac{420}{750x\sqrt{3}x0{,}946x0{,}910x\left(1{,}35x1{,}25 - 0{,}35x1{,}25^2\right)}} - 1}{0{,}55}\right)^{0{,}83} = 0{,}75\ m$$

For the conductor-structure and conductor-obstacle configurations, the calculation is the same except for the value of the gap factor. The clearance distances values are given in Table F.3.

Conductor - conductor configuration ($K_{g\_sf} = 1{,}60$):

— for fast front overvoltages

$$D_{pp} = \frac{1{,}2x1550}{530x0{,}978x0{,}961x(0{,}74 + 0{,}26x1{,}60)} = 3{,}23\ m$$

— for slow front overvoltages

$$D_{pp} = \frac{1}{0,46}\left(e^{\frac{1,4x1,05x1050}{1080x0,978x0,922x1,60}} - 1\right) = 3,68\,m$$

— for power frequency overvoltages

$$D_{50Hz\_p\_p} = \left(\frac{e^{\frac{420}{750x0,959x0,910x\left(1,35x1,60-0,35x1,60^2\right)}} - 1}{0,55}\right)^{0,83} = 1,17\,m$$

Table F.3: Clearance distances - 400 kV system

	cd [a]– window (K_{g_sf} = 1,25)	**cd [a]- structure (K_{g_sf} = 1,45)**	**cd [a]- obstacle (K_{g_sf} = 1,30)**	**cd [a]- cd (K_{g_sf} = 1,60)**
Fast front D_{el} and D_{pp}	D_{el} = 2,92 m	D_{el} = 2,78 m	D_{el} = 2,89 m	D_{pp} = 3,23 m
Slow front D_{el} and D_{pp}	D_{el} = 3,20 m	D_{el} = 2,57 m	D_{el} = 3,02 m	D_{pp} = 3,68 m
D_{50Hz}	$D_{50Hz\_p\_e}$ = 0,75 m	$D_{50Hz\_p\_e}$ = 0,70 m	-	$D_{50Hz\_p\_p}$ = 1,17 m

[a] cd: conductor.

The largest distances are given by switching overvoltages except for the internal clearance distance D_{el} which with K_{g_sf} = 1,45 is given by lightning overvoltage.

Annex G
(normative)

Earthing systems

G.1 Definition of symbols used in this annex

Symbol	Signification
A	Cross-section of the earthing conductor or earth electrode in square millimetres
G	Short-circuit current density for earthing conductor
I	Conductor current in amperes (rms value)
I_B	Current flowing through the body
I_d	Continuous current in an earthing conductor
I_E	Earth return current
I_{EW}	Current in the earth wire (in balanced stage)
K	Constant which depends on the material of the current-carrying component
R_a	Additional electrical resistance ($R_a = R_{a1} + R_{a2}$)
R_{a1}	Resistance, for example, of the footwear
R_{a2}	Resistance to earth of the standing point
r	Reduction factor of earth wires. Also called "screening factor of the earth wires"
s	Circumference of a rectangular profile conductor
t_F	Duration of the fault current in seconds
U_D	Voltage difference acting as a source voltage in the touching circuit with a limited value that guarantees the safety of a person when using additional known resistances (i.e. footwear, standing surface insulating material)
U_T	Touch voltage (V)
U_{Tp}	Permissible touch voltage, i.e. the voltage across the human body
Z_B	Total human body impedance (Ω)
Z_{EW-E}	Self impedance of the earth wire
Z_{ML-EW}	Mutual impedance between phase conductors and earth wire
β	Reciprocal of the temperature coefficient of resistance of the current-carrying component at 0 °C
θ_i	Initial temperature of the earth electrode (°C)
θ_F	Final temperature of the earth electrode (°C)
ρ_E	Resistivity of the ground near the surface (Ωm)
$3I_o$	Sum of zero sequence currents

G.2 Minimum dimensions of earth electrode materials ensuring mechanical strength and corrosion resistance

Table G.1 - Minimum dimensions of earth electrode materials

Material		Type of earth electrode	Minimum size				
			Core			Coating/sheath	
			Diameter (mm)	Cross-Section (mm^2)	Thick-ness (mm)	Single value (µm)	Average values (µm)
Steel	hot-galvanized	Strip [b]		90	3	63	70
		Profile (inc. plates)		90	3	63	70
		Pipe	25		2	47	55
		Round bar for earth rod	16			63	70
		Round bar for surface earth electrode	10				50
	with lead sheath [a]	Round wire for surface earth electrode	8			1 000	
	with extruded copper sheath	Round bar for earth rod	15			2 000	
	with electrolytic copper sheath	Round bar for earth rod	14,2			90	100
Copper	bare	Strip		50	2		
		Round wire for surface earth electrode		25 [c]			
		Stranded cable	1,8 [d]	25			
		Pipe	20		2		
	tinned	Stranded cable	1,8 [d]	25		1	5
	galvanized	Strip [b]		50	2	20	40
	with lead sheath [a]	Stranded cable	1,8 [d]	25		1 000	
		Round wire		25		1 000	

a) Not suitable for direct embedding in concrete

b) Strip, rolled or cut with rounded edges.

c) In extreme conditions where experience shows that the risk of corrosion and mechanical damage is extremely low 16 mm^2 may be used.

d) Diameter of single wire.

G.3 Current rating calculation

For fault currents which are interrupted in less than 5 seconds the cross-section of the earthing conductor or earth electrode shall be calculated from the following formula (see IEC 60724):

$$A = \frac{I}{K}\sqrt{\frac{t_F}{\ln\frac{\theta f + \beta}{\theta i + \beta}}}$$

where

A	is the cross-section in square millimetres;
I	is the conductor current in amperes (rms value);
t_F	is the duration of the fault current in seconds;
K	is a constant which depends on the material of the current-carrying component. Table G2 provides values for the most common materials;
β	is the reciprocal of the temperature coefficient of resistance of the current-carrying component at 0 °C (see Table G.2);
θ_i	is the initial temperature in degrees Celsius. Values may be taken from IEC 60287-3-1. If no value is laid down in the Project Specification or NNAs, 20 °C as ambient ground temperature at a depth of 1 m should be adopted;
θ_F	is the final temperature in degrees Celsius.

Table G.2 - Material constants

Material	β in °C	K in $As^{1/2}/mm^2$
Copper	234,5	226
Aluminium	228,0	148
Steel	202,0	78

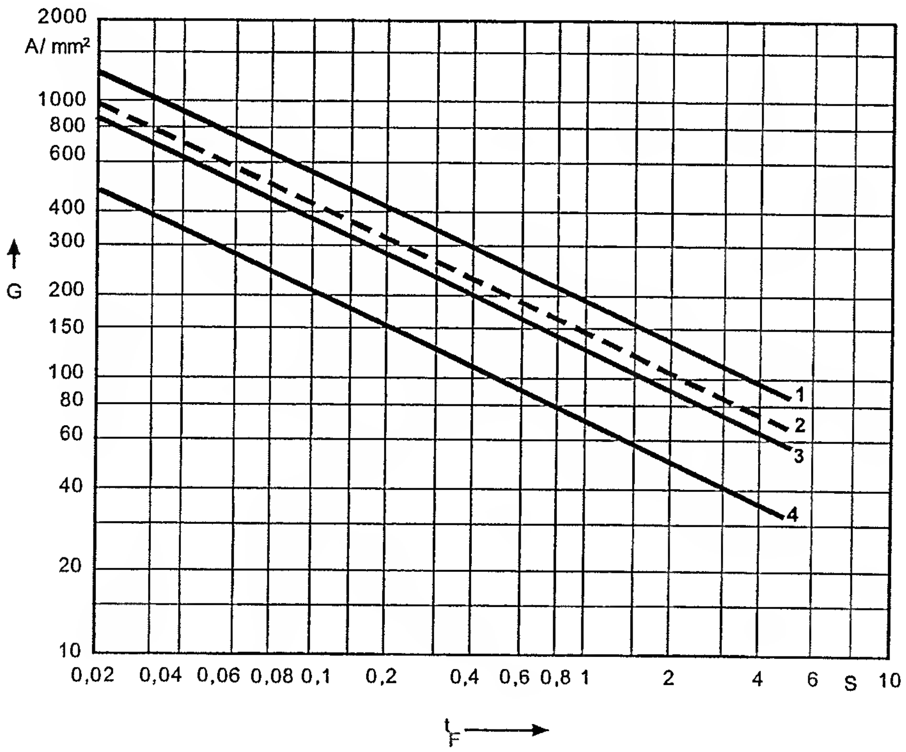
For common conditions where the earthing conductor is in air and the earth electrode is in soil the short-circuit current density G may be taken from Figure G.4 for an initial temperature of 20 °C and final temperatures up to 300 °C.

For fault currents flowing for a longer time (as in systems with isolated neutral or with resonant earthing) the recommended cross-sections are shown in Figure G.5. If a final temperature other than 300 °C (see Figure G.4, lines 1, 3 and 4) is chosen the current may be calculated with a factor selected from Table G.3:

For example lower final temperatures are recommended for insulated conductors and conductors embedded in concrete.

Table G.3 - Factors for conversion of continuous current from 300 °C final temperature to another final temperature

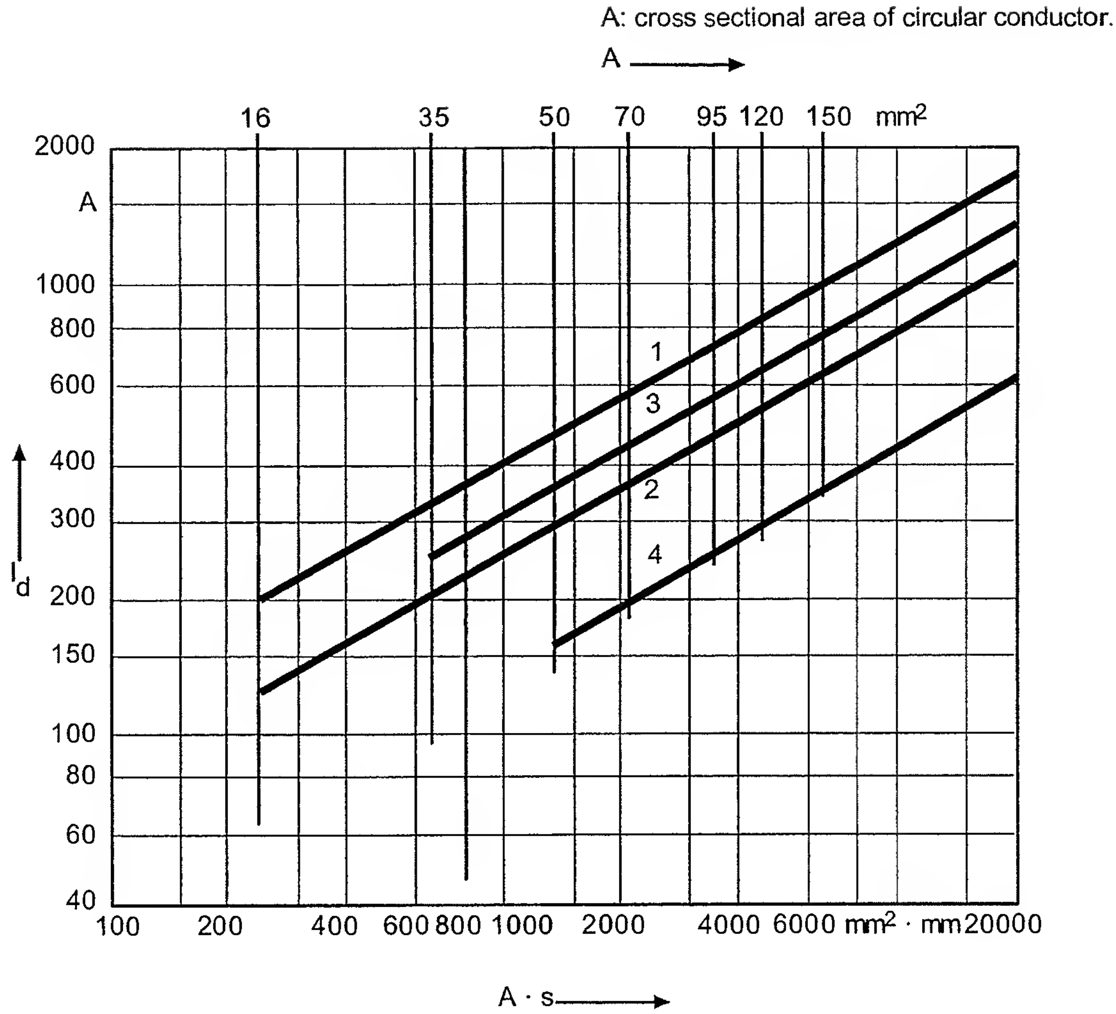
Final temperature °C	Conversion factor
400	1,20
350	1,10
300	1,00
250	0,90
200	0,80
150	0,70
100	0,60



1 Copper, bare or zinc-coated
2 Copper, tin-coated or with lead sheath
3 Aluminium only earthing conductors
4 Galvanized steel

Lines 1, 3 and 4 apply for a final temperature of 300 °C, line 2 applies for 150 °C. Table G.3 contains factors for conversion of short circuit current density relative to other final temperatures.

Figure G.4 - Short circuit current density G for earthing conductors and earth electrodes dependent on the duration of the fault current t_F



A . s: product of cross sectional area and circumference of a rectangular conductor

1 Copper, bare or zinc-coated
2 Copper, tin-coated or with lead sheath
3 Aluminium
4 Galvanized steel

Lines 1, 3 and 4 apply for a final temperature of 300 °C, line 2 applies for 150 °C. Table G.3 contains factors for conversion to other final temperatures.

Figure G.5 - Continuous current I_d for earthing conductors of circular and rectangular cross section

G.4 Touch voltage and body current

G.4.1 Equivalence between touch voltage and body current

For the calculation of permissible values of touch voltages for high voltage installations the following assumptions are made:

— current path one hand to feet;

— 50% probability factor for body impedance;

— 5% probability of ventricular fibrillation;

— no additional resistances.

NOTE These assumptions lead to a touch voltage curve with an estimated acceptable risk, taking into account the rare occurrence of earth faults in high voltage systems and the small probability of persons being present at the same time.

Assuming that the basis of body current calculation is IEC 60479-1, Revision 2 of clause 2, and taking into account as permissible limit of current the curve c2 of Figure 5 (probability of ventricular fibrillation less than 5 %, left hand to feet current path), the following table results:

Table G.6 - Permissible body current I_B depending on its duration t_F

Fault duration t_F s	Body current I_B mA
0,05	900
0,10	750
0,20	600
0,50	200
1,00	80
2,00	60
5,00	51
10,00	50

In order to obtain the relevant permissible touch voltage, it is necessary to determine the total human body impedance. This impedance depends on touch voltages and on the current path; values for a hand to hand or hand to foot current path are indicated in IEC 60479-1, from which the following table is drawn (probability of 50 % that body impedances are less than or equal to the given value).

Table G.7 - Total human body impedance Z_B related to the touch voltage U_T for a current path hand to hand or hand to foot

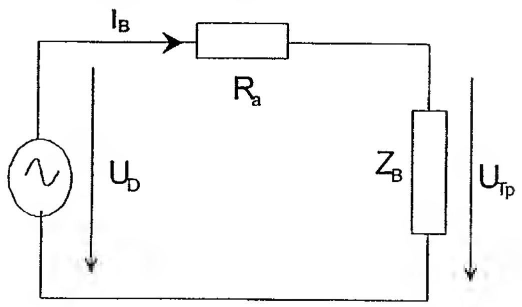
Touch voltage U_T V	Total human body impedance Z_B Ω
25	3 250
50	2 625
75	2 200
100	1 875
125	1 625
220	1 350
700	1 100
1 000	1 050

Taking into account a hand to feet current path a correction factor 0,75 for the body impedance is to be applied. By joining the two tables considering this correction factor, it is possible, by means of an iterative process, to calculate a touch voltage limit for each value of the fault duration.

Table G.8 - Fault duration related to touch voltage U_{Tp}

Fault duration t_F s	Permissible touch voltage U_{Tp} V
0,05	735
0,10	633
0,20	528
0,50	204
1,00	107
2,00	90
5,00	81
10,00	80

G.4.2 Calculation taking into account additional resistances



U_{Tp} is the permissible touch voltage, the voltage across the human body;
Z_B is the body impedance;
I_B is the current flowing through the body;
U_D is the voltage difference acting as a source voltage in the touching circuit with a limited value that guarantees the safety of a person when using additional known resistances (i.e. footwear, standing surface insulating material);
R_a is the additional resistance ($R_a = R_{a1} + R_{a2}$);
R_{a1} is, for example, the resistance of the footwear;
R_{a2} is the resistance to earth of the standing point;

Figure G.9 - Equivalent circuit for touch voltage and body current calculation

Table G.10 - Values for calculation

Type of contact	Left hand - Both feet
Probability factor for the value of Z_B not to be exceeded	50 %
Curve $I_B = f$ (t)	c2 in Figure 14 of IEC 60479-1
Circuit impedance	Z_B (50 %) + R_a
Additional resistance	$R_a = R_{a1} + R_{a2} = R_{a1}+1{,}5\ \rho_E$(*)
(*) ρ_E is the resistivity of the ground near the surface (Ω•m)	

<u>Calculation method:</u>

t_F Fault duration.

$\Downarrow$

$U_{Tp} = f\,(t_F)$ According to Table G.6 and Table G.8 using interpolation or directly from curve U_{D1} in Figure 6-2.

$\Downarrow$

$Z_B = f\,(U_{Tp})$ According to Table G.6 and Table G.7 using interpolation.
$I_B = U_{Tp}/Z_B$ Per definition.

$\Downarrow$

$$U_D(t_F) = U_{Tp}(t_F) + (R_{a1} + R_{a2})\cdot I_B = U_{Tp}(t_F) + R_a\cdot U_{Tp}(t_F)/Z_B = U_{Tp}(t_F)\cdot(1 + R_a/Z_B)$$

The diagram in Figure 6.2 shows curves $U_D = f(t_F)$ for 4 values of R_a:

$R_a = 0\ \Omega$;

$R_a = 1\,750\ \Omega$, $R_{a1} = 1\,000\ \Omega$, $\rho_E = 500\ \Omega \bullet m$;

$R_a = 4\,000\ \Omega$, $R_{a1} = 1\,000\ \Omega$, $\rho_E = 2\,000\ \Omega \bullet m$;

$R_a = 7\,000\ \Omega$, $R_{a1} = 1\,000\ \Omega$, $\rho_E = 4\,000\ \Omega \bullet m$.

G.5 Measuring touch voltages

For touch voltage measurements a current injection method shall be used (see H.4).

There are two alternative aceptable methods as follows:

1) The touch voltage is determined by taking into account the human body with a resistance of 1 kΩ.

   The measuring electrode(s) for simulation of the feet shall have a total area of 400 cm^2 and shall be pressed on the earth with a minimum total force of 500 N. Alternatively, a probe, driven at least 20 cm into the earth, may be used instead of the measuring electrode. For the measurement of the touch voltage in any part of the installation the electrode shall be placed at a distance of 1 m from the exposed part of the installation: for concrete or dried soil it should be on a wet cloth or water film. A tip-electrode for the simulation of the hand shall be capable of piercing a paint coating (not acting as insulation) reliably. One terminal of the voltmeter is connected to the hand electrode, the other terminal to the foot electrode. It is sufficient to carry out such measurements as a sampling test.

   NOTE In order to get a quick indication of the upper limit of touch voltages, measurement by a voltmeter with a high internal resistance and a probe driven 10 cm deep is often sufficient.

2) The touch voltage is determined by measuring the driving voltage U_D (Figure G.9) using a high impedance voltmeter and calculating the touch voltage as described in G.4.2. For the measurement of the driving voltage in any part of the installation the electrode shall be placed at a distance of 1 m from the exposed part of the installation.

   One terminal of the voltmeter is connected to the exposed part and the other terminal to the foot electrode, a probe driven at least 20 cm into earth.

G.6 Reduction factor related to earthwires of overhead lines

G.6.1 General

Earth wires of overhead lines participate in carrying fault currents returning to earth. They carry or transmit a part of the earth fault current of the corresponding circuit. By this effect the earthing system of a high voltage installation affected by an earth fault will be more effective in discharging the earth fault current. The extent of this relief is described by the reduction factor.

The reduction factor r for an earth wire of a 3-phase overhead line is the ratio of the earth return current to the sum of the zero sequence currents of the 3-phase circuit.

$$r = I_E/3I_0 = (3I_0 - I_{EW})/3I_0$$

where

I_{EW} is the current in the earth wire (in balanced stage);
I_E is the earth return current;
$3I_o$ is the sum of zero sequence currents.

For the balanced current distribution of an overhead line the reduction factor of an earth wire can be calculated on the basis of the self impedance of the earth wire $Z_{EW\text{-}E}$ and the mutual impedance between phase conductors and earth wire $Z_{ML\text{-}EW}$:

$$r = (Z_{EW\text{-}E} - Z_{ML\text{-}EW})/Z_{EW\text{-}E} = 1\text{-}(Z_{ML\text{-}EW}/Z_{EW\text{-}E})$$

The most influential characteristic for $Z_{ML\text{-}EW}$ is the mean distance between phase conductors and earth wire and for $Z_{EW\text{-}E}$ the resistance of the earth wire. It follows that, the reduction effect of an earth wire in respect of the earth current increases (r tending to be small) with lower distance between phase conductors and earth wire and with lower resistance of the earth wire.

G.6.2 Values of reduction factor of overhead lines

The values of reduction factors vary within the range 0,2 to 1 and are dependent on several parameters, e.g: line geometry, location of earth wire(s) to phase conductors, soil resistivity, number of earth wires and their resistance.

Annex H
(informative)

Earthing systems

H.1 Definition of symbols used in this annex

Symbol	Signification
D	L/π Diameter of the ring earth electrode
d	Diameter of the stranded earth electrode or half width of an earth strip/Diameter of the earth rod
I_0	Zero sequence current during fault
I_E	Current to earth during fault
I_m	Measured test current
L	Length of the earth strip/length of the earth rod
R_E	Resistance to earth
R_{ER}	Ring earth electrode resistance
R_{ES}	Strip earth electrode resistance
R_t	Tower footing resistance
r	Reduction factor of earth wires. Also called "screening factor of earth wires"
U_E	Earth potential rise
U_{em}	Measured voltage between the earthing system and a probe in the area of the reference earth
Z_E	Impedance to earth, for example from the measurement or from the calculation
Z_S	Earth wire impedance of one span
ρ_E	Soil resistivity in $\Omega \cdot m$

H.2 Basis for the verification

H.2.1 Soil resistivity

The soil resistivity ρ_E varies considerably at different locations according to the type of soil, grain size, density and moisture (see Table H.1).

Table H.1 - Soil resistivities for alternating frequency currents (ranges of values, which were frequently measured)

Type of soil	Soil resistivity ρ_E in Ω•m
Marshy soil	5 to 40
Loam, clay, humus	20 to 200
Sand	200 to 2 500
Gravel	2 000 to 3 000
Weathered rock	mostly below 1 000
Sandstone	2 000 to 3 000
Granite	up to 50 000
Moraine	up to 30 000

Up to some metres of depth changes of moisture can cause temporary variations of the soil resistivity. Furthermore, it has to be considered that the soil resistivity can change considerably with the depth because of distinctly different layers of soil which are usually present.

H.2.2 Resistance to earth

The resistance to earth R_E of an earth electrode depends on the soil resistivity as well as on the dimensions and the arrangement of the earth electrode. It depends mainly on the length of the earth electrode and less on the cross-section. Figures H.2 and H.3 show the values of the resistance to earth for surface earth electrodes or earth rods, respectively, relative to the total length.

In the case of very long surface earth electrodes (for example cables with earth electrode effect) the resistance to earth decreases with the length, but approaches a final value. Foundation earth electrodes may be regarded as earth electrodes buried in the surrounding soil.

The resistance to earth of a meshed earth electrode is approximately:

$$R_E = \frac{\rho_E}{2D}$$

where

D is the diameter of a circle with the same area as the meshed earth electrode.

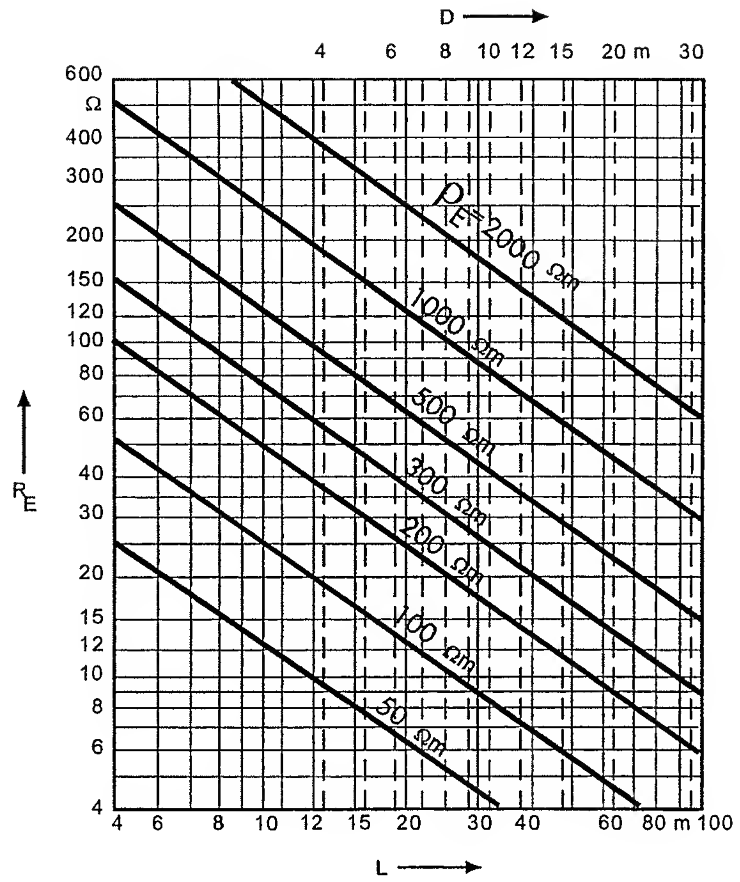


Figure H.2 - Resistance to earth R_E of surface earth electrodes (made from strip, round material or stranded conductor) for straight or ring arrangement in homogenous soil

Calculated values according to the following formulas:

— strip earth electrode resistance: $R_{ES} = (\rho_E/\pi L)\ \ln(2L/d)$;

— ring earth electrode resistance: $R_{ER} = (\rho_E/\pi^2 D)\ \ln(2\pi D/d)$.

where

L	is the length of the earth strip;
D	is the diameter of the ring earth electrode $=L/\pi$;
d	is the diameter of the stranded earth electrode or half width of an earth strip (assumed here as 15 mm);
ρ_E	is the soil resistivity in Ω•m;
π	is the number 3,1416

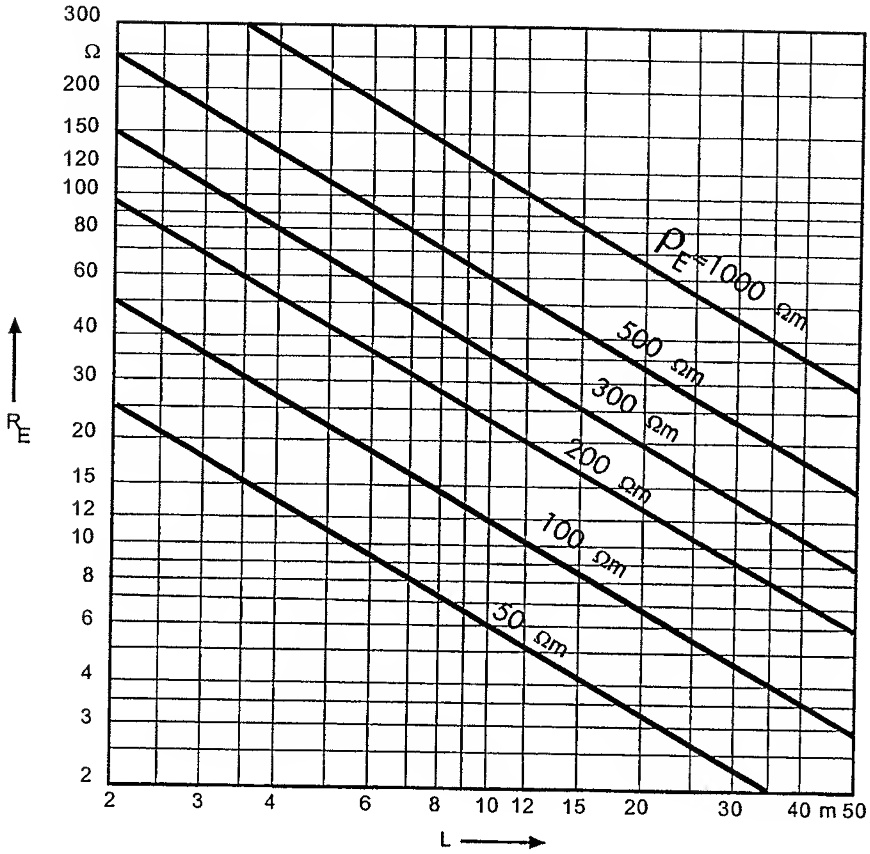


Figure H.3 - Resistance to earth R_E of earth rods, vertically buried in homogeneous soil

Calculated values according to the following formula:

$$R_E=(\rho_E/2\pi L)\cdot \ln(4L/d)$$

where

L	is the length of the earth rod;
d	is the diameter of the earth rod (here 20 mm assumed);
ρ_E	is the soil resistivity in Ω•m.
π	is the number 3,1416

H.3 Installation of earth electrodes and earthing conductors

H.3.1 Installation of earth electrodes

H.3.1.1 Horizontal earth electrodes

Horizontal earth electrodes are usually laid at the bottom of a trench or a foundation excavation.

It is recommended that:

- they are surrounded with lightly tamped soil,
- stones or gravel should not be in direct contact with the buried earth electrodes,
- indigenous soil which is corrosive to the electrode metal used should be replaced by a suitable backfill.

H.3.1.2 Vertical or inclined driven rods

Vertical or inclined driven rods are driven into the soil by force and should be separated by a distance not less than the length of the rod.

Appropriate tools should be used to avoid any damage to the electrodes when driving them in.

H.3.1.3 Jointing the earth electrodes

The joints used to connect conductive parts of an earth electrode network (grid) within the network itself should have adequate dimensions to ensure an electrical conductance and mechanical and thermal strength equivalent to the electrodes themselves.

The earth electrodes should be resistant to corrosion and should not be liable to contribute to galvanic cells.

The joints used to assemble rods should have the same mechanical strength as the rods themselves and should resist mechanical stresses during driving. When different metals, which form galvanic cells possibly causing galvanic corrosion, have to be connected, joints should be protected by durable means against contact with electrolytes in their surroundings.

H.3.2 Installation of earthing conductors

In general the path of the earthing conductors should be as short as possible.

H.3.2.1 Installing the earthing conductors

The following installation methods may be considered:

- buried earthing conductors: only protection against mechanical damage is required,
- accessible installed earthing conductors: above the ground the earthing conductors should be installed in such a way that they remain accessible. If there is a risk of mechanical damage, the earthing conductor should be adequately protected,

— concrete embedded earthing conductors: earthing conductors may also be embedded in concrete. Easily accessible terminals should be available at both ends.

Special attention should be taken to avoid corrosion where the bare earthing conductor enters the soil or concrete.

H.3.2.2 Jointing the earthing conductors

The joints should have good electrical continuity to prevent any unacceptable temperature rise under fault current conditions.

Joints should not become loose and should be protected against corrosion. When different metals, which form galvanic cells which can cause galvanic corrosion, have to be connected, joints should be protected by durable means against any contact with electrolytes in their surroundings.

Suitable connectors should be used to connect the earthing conductor to the earth electrode, to the main earth terminal and to any metallic part.
It should be impossible to disassemble joints without tools.

H.4 Measurements for and on earthing systems

H.4.1 Measurement of soil resistivities

Measurements of the soil resistivity for the pre-determination of the resistance to earth or the impedance to earth should be carried out according to a four probe method (for example Wenner-method), whereby the soil resistivity for different depths can be determined.

H.4.2 Measurement of resistances to earth and impedances to earth

These resistances and impedances can be determined in different ways. Which method is suitable depends on the extent of the earthing system and the degree of interference and disturbance voltages.

NOTE Attention should be given to the fact that while the measurements and preparations are carried out, even when disconnected, but especially during the measurement on and between earthed parts (for example between tower and lifted-off earth wire), dangerous touch voltages can occur.

Examples of suitable methods of measurements and types of instruments are:

a) Fall-of-potential method with the earth tester

   This instrument is used for earth electrodes and earthing systems of small or medium extent, for example single rod earth electrodes, strip earth electrodes, earth electrodes of overhead line towers with lifted off or attached earth wires, high voltage earthing systems and separation of the low-voltage earthing systems. The frequency of the alternating voltage used should not exceed 150 Hz.

   The earth electrode under test, probe and auxiliary electrode should lie in a straight line as far apart as possible. The distance of the probe from the earth electrode under test should be at least 2,5 times the maximum extension of the earth electrode under test (in the measuring direction), but not less than 20 m; the distance of the auxiliary electrode should be at least 4 times, but not less than 40 m.

b) High frequency earth tester

This instrument facilitates, without lifting-off the earth wire, the measurement of the resistance to earth of a single tower. The frequency of the measuring current should be so high that the chain impedance of the earth wire and the neighbouring towers becomes high, representing a practically negligible shunt circuit to the earthing of the single overhead line tower.

c) Heavy-current injection method

This method is used particularly for the measurement of the impedance to earth of large earthing systems, but also if transferred potentials (i.e. metallic pipes) are to be taken into account and therefore greater distances between the earthing system of the relevant tower and the remote earth electrode are necessary.

By applying an alternating voltage of approximately system frequency between the earthing system and a remote earth electrode, a test current $\mathbf{I_m}$ is injected into the earthing system, leading to a measurable potential rise of the earthing system.

Earth wires and cable sheaths with earth electrode effect, which are operationally connected to the earthing system, should not be disconnected for the measurement.

The modulus of the impedance to earth Z_E is given by:

$$Z_E = \frac{U_{em}}{I_m \cdot r}$$

where

U_{em} is the measured voltage between the earthing system and a probe in the area of the reference earth (remote earth) in volts;

I_m is the measured test current in amperes;

r is the reduction factor of earth wires.

The reduction factor may be determined by calculation or by measurement.

For overhead lines without earth wires r = 1.

Earth wires of lines which run on separate supports parallel to the test line between earthing system and remote earth electrode, should be taken into account, if they are connected to the earthing system under test.

The distance between the tested earthing system and the remote earth electrode should, as far as possible be not less than 5 km. The test current should, as far as possible, be selected at least so high, that the measured voltages are greater than possible interference and disturbance voltages. This is generally ensured for test currents above 50 A. The internal resistance of the voltmeter should be at least 10 times the resistance to earth of the probe.

NOTE For small earthing systems smaller distances and test currents can be sufficient. Possible interference and disturbance voltages should be taken into account.

H.4.3 Determination of the earth potential rise

The earth potential rise U_E is given by:

$$U_E=Z\cdot I_E$$

where

I_E is the current to earth;

Z_E is the impedance to earth, for example from the measurement or from the calculation. The aproximate calculation taking into account earth wires and the neighbouring towers effect can be made using equation.

$$Z_E = 0,25\cdot\left(Z_S + \sqrt{Z_S\cdot(4\cdot R_t + Z_S)}\right)$$

where

Z_S is the earth wire impedance of one span;

R_t is the tower footing resistances.

The current to earth during fault is given by:

$$I_E = r\cdot 3I_0$$

where

r is the reduction factor of earth wires;

I_0 is the zero sequence current during fault.

Annex J
(normative)

Lattice steel towers

In the following clauses reference is made to the corresponding chapters of ENV 1993-1-1 in brackets.

J.1 Definition of symbols used in this annex

Symbol	Signification
A	Cross section area; gross cross section area of bolt
A_{eff}	Effective cross section area
A_{net}	Net cross section at holes
A_s	Tensile stress area of bolt
b	Nominal width
b_{eff}	Effective width of the leg
c	Distance between batten plates
d	Bolt diameter
d_0	Hole diameter
E	Modulus of elasticity
e_1	End distance from centre of hole to adjacent end in angle
e_2	Edge distance from centre of hole to adjacent edge in angle
F	Concentrated horizontal load
f_u	Ultimate tensile strength
f_{ub}	Ultimate tensile strength for bolt
f_y	Yield strength
f_{yd}	Design yield strength
i	Radius of gyration about the relevant axis
L	System length
$M_{c\ Rd}$	Design moment of resistance in bending
M_{sd}	Bending moment at cross section
m	Number of angles
N	Axial force
N_d	Compression force ; force in the compression member
$N_{R,d}$	Design value of the buckling resistance
N_{sd}	Design value of the tensile or compressive force at cross section
P_1	Spacing of 2 holes in the direction of load transfer
p	Spacing of 2 holes, measured perpendicular to the member axis
S_d	Tension force ; force in the supporting member (tension or compression)
s	Staggered pitch, spacing of centres of 2 consecutive holes
t	Thickness
W_{eff}	Effective cross section modulus

γ_{M1}	Partial safety factor for resistance of member in bending or tension or to buckling
γ_{M2}	Partial safety factor for resistance of net section at bolt holes
γ_{Mb}	Partial safety factor for resistance of bolted connections
λ	Slenderness ratio for the relevant buckling load
λ_{eff}	Effective slenderness
$\bar{\lambda}$	Non-dimensional slenderness for the relevant buckling load
λ_p	Ratio of width to thickness (b/t)
ρ	Reduction factor
χ	Reduction factor

J.2 Classification of cross sections (Chapter 5.3)

J.2.1 Basis

Members of different shapes can be employed for transmission towers, but the most commonly adopted shapes are angles and the present normative annex deals with this type of member only, either hot rolled or cold formed.

J.2.2 Classification (Chapter 5.3.2)

All sections are considered to be class 3 or 4 according to 5.3.2 of ENV 1993-1-1.

J.2.3 Effective cross-section properties for compression members (Chapter 5.3.5)

The effective cross-section properties shall be based on the effective width b_{eff} of the leg.

In the case of unequal leg angle, each leg is considered in turn and the effective cross section is calculated as the gross section minus the reduction of section of each leg.

In the case of an angle connected by one leg, the reduction applies only to the connected leg, due to the free leg being partially in tension.

The effective width shall be obtained from the nominal width b of the leg, assuming uniform stress distribution, as follows :

$$\lambda_p = b/t$$

$$\bar{\lambda}_p = \lambda_p / \left(28{,}4\varepsilon\sqrt{K_\sigma}\right) \quad \text{with } K_\sigma = 0{,}43 \text{ and } \varepsilon = \sqrt{\left(235/f_y\right)}, f_y \text{ in MPa}$$

$$b_{eff} = \rho b$$

where

t	is the thickness
b	is the nominal width
ρ	is the reduction factor as follows

For rolled angles

when	$\bar{\lambda}_p$	$\leq 0,91$	$\rho = 1$
	$0,91 < \bar{\lambda}_p$	$\leq 1,213$	$\rho = 2 - \bar{\lambda}_p / 0,91$
	$\bar{\lambda}_p$	$> 1,213$	$\rho = 0,98 / \bar{\lambda}_p^2$

For cold formed angles

when	$\bar{\lambda}_p$	$\leq 0,809$	$\rho = 1$
	$0,809 < \bar{\lambda}_p$	$\leq 1,213$	$\rho = (5 - \bar{\lambda}_p / 0,404) / 3$
	$\bar{\lambda}_p$	$> 1,213$	$\rho = 0,98 / \bar{\lambda}_p^2$

b_{eff} shall be used to calculate effective cross section area A_{eff} and modulus W_{eff}.

These dispositions concerning the case of cold formed angles may be replaced by the requirements of ENV 1993-1-3 when available.

The effective cross section, instead of gross cross section, generally need not be considered in the elastic global analysis.

J.3 Section properties (Chapter 5.4.2)

J.3.1 Gross cross section (Chapter 5.4.2.1)

Gross cross section properties shall be determined using the specified dimensions; holes for fasteners need not be deducted. Splice materials shall not be included.

J.3.2 Net area (Chapter 5.4.2.2)

1) The net sectional area of an angle connection through both legs shall be taken as the sum of the net areas of the two legs.

2) The net area shall be taken as the gross area less an appropriate deduction for all the holes. If the holes are staggered, two values for the net area shall be calculated and the lower value shall be regarded as the net area.

   - The first value is obtained by deduction from the gross area of the areas of all the holes in a section perpendicular to the axis of the angle.
   - The second value is obtained by deduction from the gross area of the areas of all the hole sections in any diagonal or zigzag line extending progressively across the member or part of it, and then adding $s^2t/(4p)$ for each gauge (oblique) space. ($s \neq 0$ as shown in Figure J.1).

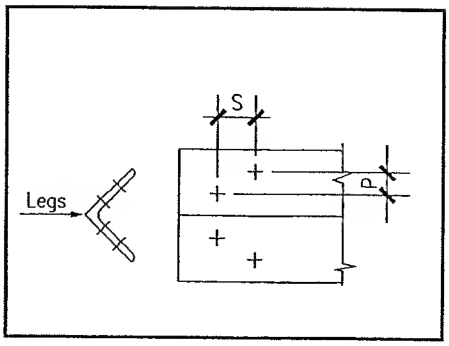


Figure J.1 - Staggered holes

where

- s is the pitch of two staggered holes measured along the axis of the member
- p is the pitch of the same two holes measured perpendicularly to the axis of the member
- t is the thickness of the material of the member

3) The net sectional area of an angle connected through one leg at the end of the member shall be taken as the net area of the connected leg, plus half of the area of the unconnected leg.

4) In case of connection with one bolt only, the net area shall be taken as the net area of the connected leg.

J.4 Check of cross section resistance

J.4.1 Tension (Chapter 5.4.3)

For a member in axial tension, the design value of the tensile force N_{sd} shall satisfy the following limits :

1) Case of two legs connected

$$N_{sd} \leq 0,9\ A_{net}\ f_u / \gamma_{M2}$$

2) Case of one leg connected, as Figure J.2

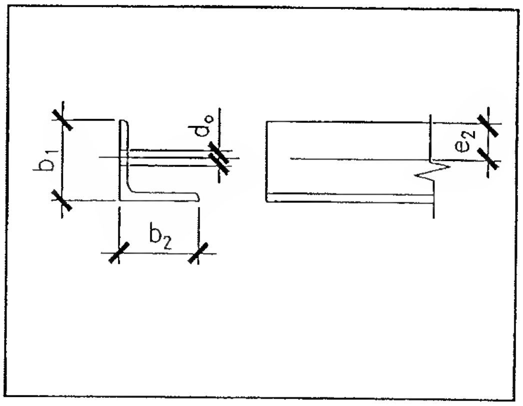


Figure J.2 - Angle with one leg connected

with 1 bolt

$$N_{sd} = (b_1 - d_0)\ t\ f_u / \gamma_{M2}$$

with 2 or more bolts

$$N_{sd} = \left(b_1 - d_0 + \frac{b_2}{2}\right)\ t\ f_u / \gamma_{M2}$$

In case of welded connections, reference shall be made to 6.6.10 of ENV 1993-1-1.

J.4.2 Compression (Chapter 5.4.4)

The design value of the compressive force N_{sd} at each cross section shall satisfy

$$N_{sd} \leq A_{eff}\ f_y / \gamma_{M1}$$

J.4.3 Bending moment (Chapter 5.4.5)

The design moment of resistance of a cross section without bolt holes shall be determined as follows :

$$M_{c\ Rd} = W_{eff}\ f_y / \gamma_{M1}$$

where:

W_{eff} is the effective section modulus consistent with A_{eff}.

J.4.4 Bending and axial forces (Chapter 5.4.8.3)

The cross section without bolt holes, is considered satisfactory if the following criteria is satisfied:

$$\frac{N_{sd}}{A_{eff}\ f_{yd}} + \frac{M_{sdyy}}{W_{effyy}\ f_{yd}} + \frac{M_{sdzz}}{W_{effzz}\ f_{yd}} \leq 1$$

where:

- A_{eff} and W_{eff} of angle sections are defined in J.2.3
- For A_{eff} and W_{eff} of other sections reference shall be made to 5.3 and 5.4.5 of ENV 1993-1-1.
- $f_{yd} = f_y / \gamma_{M1}$.

When determining the effective cross-sectional data A_{eff} and W_{eff} only the reducing effects for cross-sectional parts under compression shall be considered.

J.5 Check of the buckling resistance of members (Chapter 5.5)

J.5.1 Compression members (Chapter 5.5.1)

J.5.1.1 Flexural buckling

For members in axial compression, the design value of the compression force, N_d, divided by the design value of the buckling resistance, $N_{R,d}$, shall satisfy :

$$\frac{N_d}{N_{R,d}} \leq 1$$

The design buckling resistance is defined by

$$N_{R,d} = \chi \ A_{eff} \ f_y \ / \gamma_{M\,1}$$

The reduction factor χ is given by the formula 5.46 in ENV 1993-1-1, and depends on :

- the slenderness ratio λ
- the material properties E and f_y
- the buckling curve

The tower design shall be done :

- by calculation only or
- by calculation validated by a full scale loading test.

If the design is done by calculation only the following design procedure shall be applied:

- the appropriate buckling curve to be used shall be the curve from 5.5.1 of ENV 1993-1-1 with imperfection factor $\alpha = \boxed{0,49}$.
- the appropriate slenderness λ shall be determined according to clauses J.6 and J.7, where the boxed values may be replaced by values given in NNA's.
- the reduction factor χ is then calculated using formula 5.46 in ENV 1993-1-1, with :

$$\bar{\lambda} = \frac{\lambda}{\pi}\sqrt{\frac{f_y}{E}\frac{A_{eff}}{A}}$$

If the design is done by calculation and validated by documented full scale loading tests the following design procedure shall be applied :

- the appropriate buckling curve to be used shall be the curve b from 5.5.1 of ENV 1993-1-1
- the appropriate slenderness λ shall be determined according to J.6 and J.7, without changing the boxed values.
- the non-dimensional slenderness $\bar{\lambda}$ for the relevant buckling load in equation 5.4.6. of ENV 1993-1-1 is replaced by the effective slenderness $\bar{\lambda}_{eff}$ determined from clauses J.8 and J.9.
- the reduction factor χ is then calculated using formula 5.46 in ENV 1993-1-1.

The NNA or the Project Specification shall state to what extent the full scale loading tests are required.

These subclauses override 5.8 of ENV 1993-1-1.

J.5.1.2 Flexural torsional buckling

The slenderness ratio $\overline{\lambda}$ for flexural torsional buckling shall be calculated by an accepted formula and shall then be used in the calculation of the reduction factor χ as explained in J.5.1.1
For angles with equal legs the slenderness ratio for flexural torsional buckling may be calculated approximately by using the formula:

$$\overline{\lambda}_p = \frac{5\,b}{\pi\,t}\sqrt{\frac{f_y}{E}\frac{A_{eff}}{A}}$$

J.5.2 Lateral torsional buckling of beams (Chapter 5.5.2)

The design buckling resistance moment of a laterally unrestrained beam shall be determined in accordance with the provisions given in 5.5.2 of ENV 1993-1-1, due account being taken of J.5.1 above.

J.5.3 Bending and axial tension (Chapter 5.5.3)

The provisions given in 5.5.3 of ENV 1993-1-1 shall be followed.

J.5.4 Bending and axial compression (Chapter 5.5.4)

The provisions given in 5.5.4 of ENV 1993-1-1 shall be followed, due account being taken of J.5.1 above.

J.6 Buckling length of members

J.6.1 General

1) There are several different configurations, which are commonly used in lattice towers, and each requires separate consideration.
2) The buckling length, and hence the capacity of a member depends on the type of bracing used to stabilise the member.
3) The appropriate slenderness λ for the relevant buckling mode shall be determined from J.6.2 and J.6.3.

J.6.2 Leg members and chords

J.6.2.1 General

— The recommended maximum slenderness ratio for leg members and chords should not exceed $\boxed{120}$.
— The cross section of members usually consists of one profile. For compound member reference shall be made to J.6.4.

J.6.2.2 Single members

Several cases need to be considered, as shown in Figure J.3, and the slenderness ratio for angles shall be taken as:

Leg with symmetrical bracing (a) (b)	$\lambda = \boxed{1,0}\ L/i_{vv}$
Leg with intermediate transverse support (c)	$\lambda = \boxed{1,0}\ L/i_{yy}$
Leg with staggered bracing (d)	$\lambda = \boxed{1,0}\ L/i_{yy}$

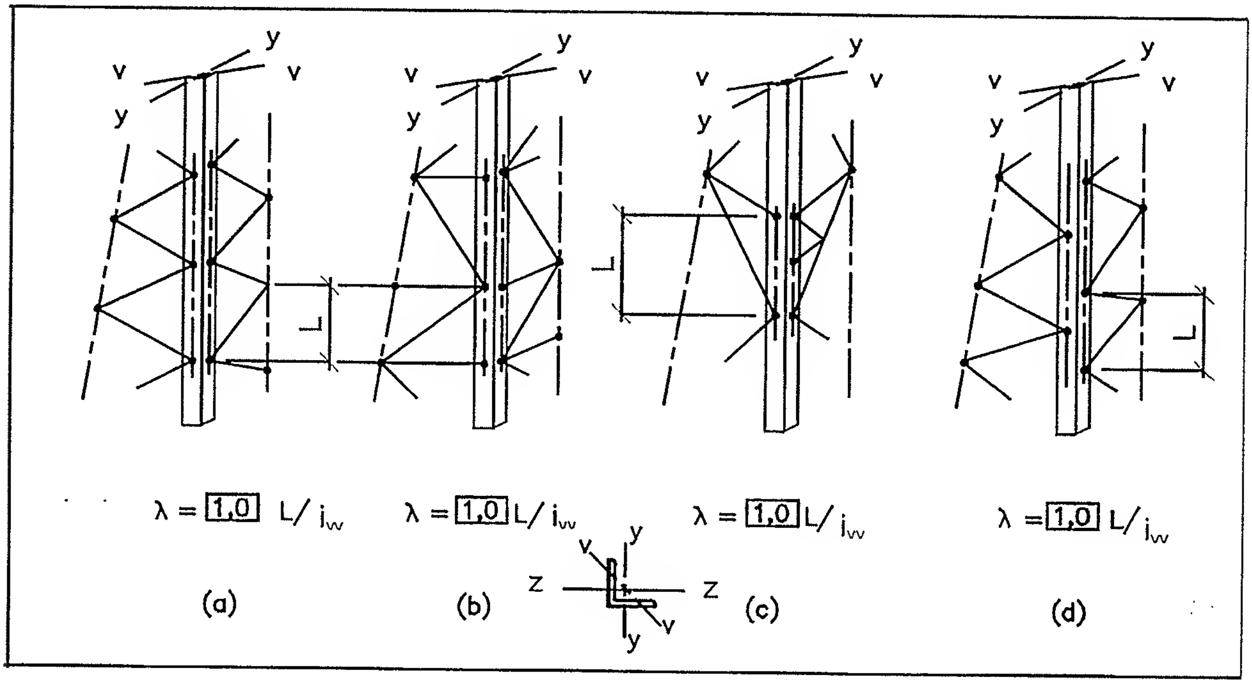


Figure J.3 - Symmetrical and staggered bracing to legs

J.6.3 Bracing patterns

J.6.3.1 General

1) Typical primary bracing patterns are shown in Figure J.4. Secondary bracings can be used to subdivide the primary bracing or main leg members as shown, for example, in Figure J.5.

2) It is good practice to have primary bracing members generally limited to a slenderness ratio of $\boxed{200}$ and secondary bracings limited to $\boxed{240}$.
Other slenderness ratios are provided for special cases in J.6.3.4.(2), J.6.3.5.(3), J.6.3.7.(2) and J.7.2.(5).

3) The cross section of bracing members usually consists of one profile.
For compound members reference is made to J.6.4.

4) In case of long members, it may be appropriate to take account of bending stresses induced by wind acting on members, in addition to the axial load.

5) The slenderness ratio λ of bracing members depends -among other things- on the end connections characterised by restraints and eccentricities.
In the following the influence of these end connections is neglected by using boxed values $\boxed{1,0}$ in the λ-formulas. In the case of calculation not validated by loading test (see J.5.1.1) special values, which take account of the above effects, may be given in the NNAs.

6) The angle between a main member and a bracing shall not be less than 15°.

J.6.3.2 Single lattice

A single lattice is commonly used where the loads are light and the lengths relatively short, as for instance near the top of lattice towers (see Figure J.4(a)). The slenderness ratio shall be taken as:
$\lambda = \boxed{1,0}\ L / i_w$

In the case of Figure J.4(b) for angles $\lambda = \boxed{1,0}\ L_1 / i_w$ and $\lambda = \boxed{1,0}\ L_2 / i_{yy}$

J.6.3.3 Cross bracing

1) Provided that both members are continuous (see Figure J.4(c)) and fixed together with at least one bolt, the intersection of the cross may be considered as a point of full restraint in the plane of the bracing. The buckling length is therefore: $\boxed{1,0}\ .\ L_1$ and the slenderness ratio shall be taken as:
$\lambda_1 = \boxed{1,0}\ L_1 / i_w$

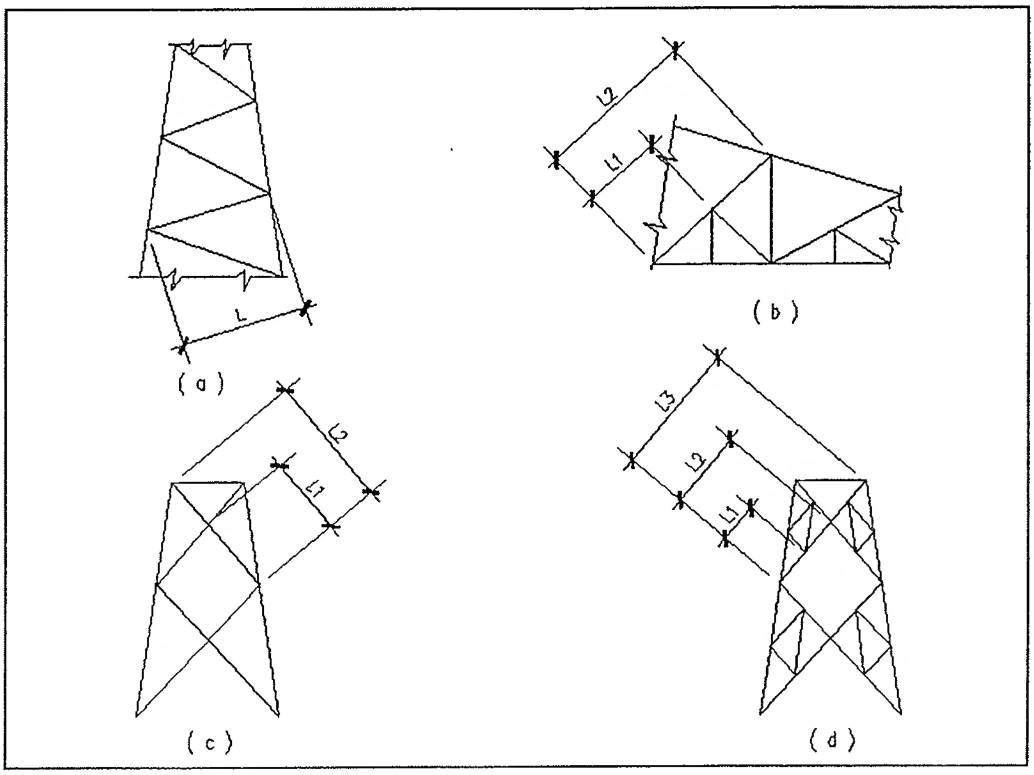


Figure J.4 - Typical bracing patterns

2) The restraint transverse to the plane of bracing depends on the ratio $|S_d|/|N_d|$,

with S_d = force in the supporting member (tension or compression)
N_d = force in the compression member,

and the following additional slenderness ratios, λ_2 , shall be considered:

S_d = tension force and $|S_d|/|N_d| \geq 2/3$

$$\lambda_2 = \lambda_1 = \boxed{1{,}0}\, L_1 / i_{vv} \text{ (full restraint)}$$

S_d = tension force and $|S_d|/|N_d| < 2/3$

$$\lambda_2 = \boxed{1{,}0}\, \frac{L_1}{i_{yy}} \sqrt{2 - 1{,}5\,|S_d|/|N_d|}$$

S_d = compression force and $|S_d|<|N_d|$

$$\lambda_2 = \boxed{1{,}0}\, \frac{L_1}{i_{yy}} \sqrt{2 + 2|S_d|/|N_d|}\ \text{, with}\quad \lambda_2 \leq \frac{L_2}{i_{yy}}$$

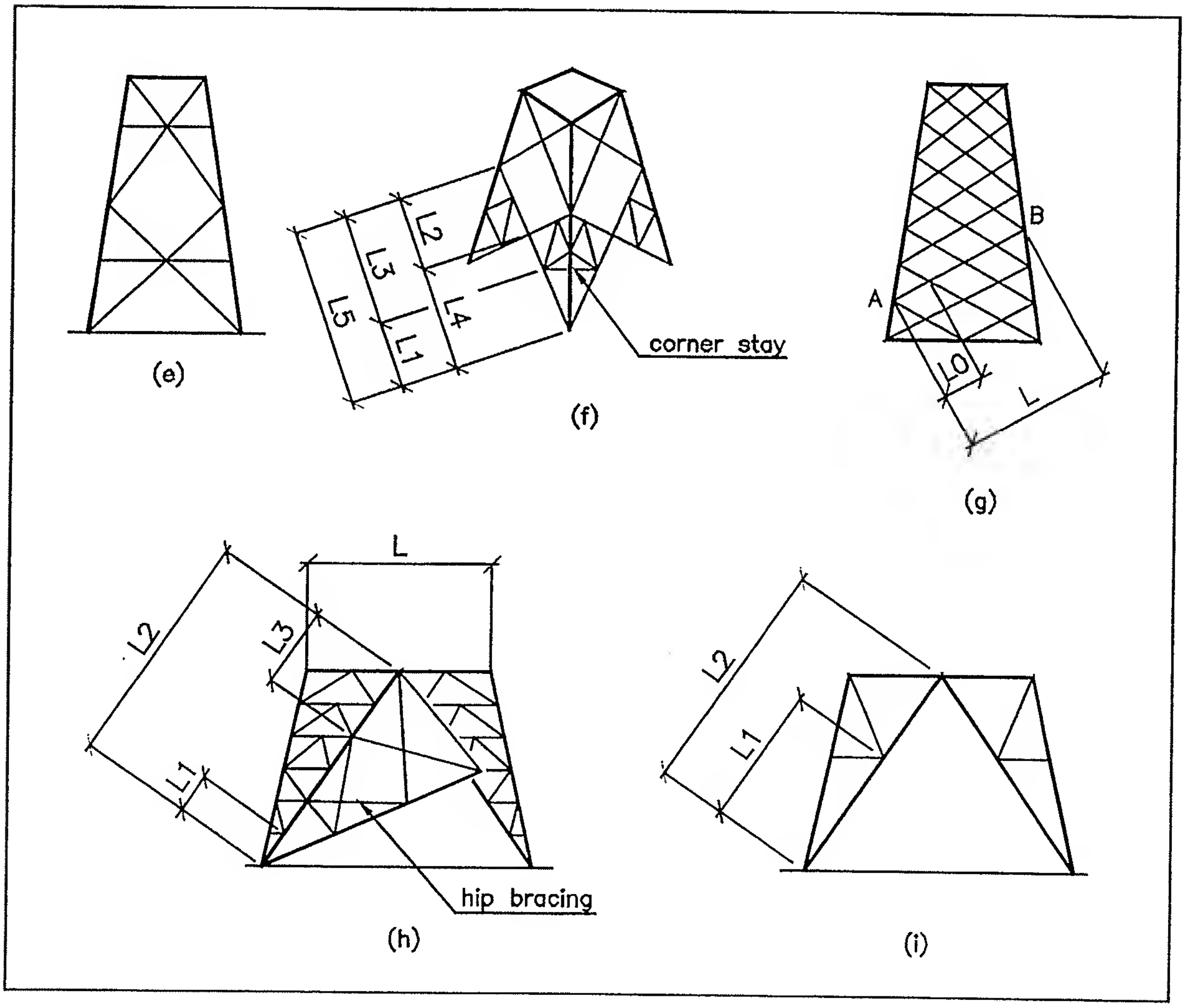


Figure J.5 - Use of secondary bracing system

J.6.3.4 Cross bracing with redundant members

1) Where redundant members are inserted to stabilise the legs (see Figure J.4(d)), they also reduce the buckling length on the axis of the minimum inertia to L_1. The slenderness ratio shall be taken as:

$\lambda_1 = \boxed{1,0}\ L_1 / i_{vv}$

2) Buckling shall be checked over the length L_2 on the rectangular axis for buckling transverse to the bracing

$\lambda_2 = \boxed{1,0}\ L_2 / i_{yy}$

multiplied by appropriate factor, depending on $|S_d|/|N_d|$, as J.6.3.3(2).

3) The slenderness ratio of the whole cross bracing length L_3 (see Figure J.4(d)) calculated on the transverse axis yy shall not exceed $\boxed{350}$.

J.6.3.5 Discontinuous cross bracing with a continuous horizontal member at centre intersection (see Figure J.6)

1) The horizontal member shall be sufficiently stiff in the transverse direction, to provide restraints for the load cases where the compression in one member exceeds the tension in the other or both members are in compression (see Figure J.5(e)).

2) This criterion shall be satisfied by ensuring that the horizontal member withstands (as a strut over its full length on the rectangular axis yy) the algebraic sum of the load in the two members of the cross brace resolved in the horizontal direction.(see Figure J.6).

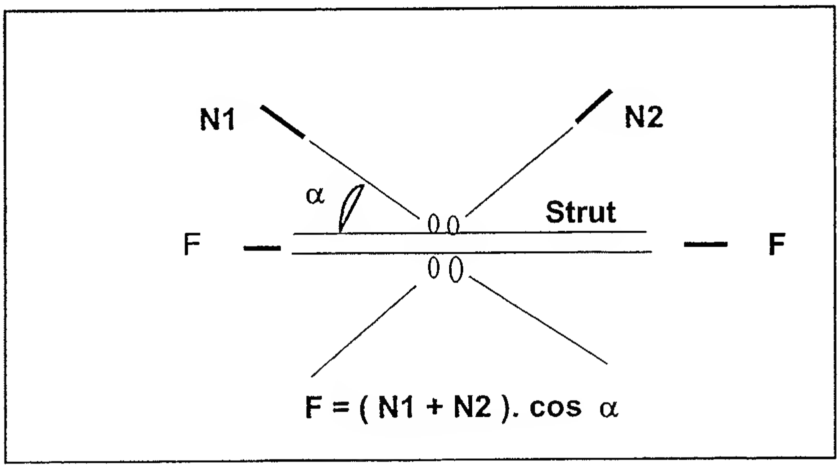


Figure J.6 - Discontinuous cross bracing

3) The maximum slenderness of the horizontal member shall not exceed $\boxed{250}$.

J.6.3.6 Multiple lattice bracing

1) In addition to the bracing design calculation, the angle bracing members of a multiple lattice configuration connected at all intersections shall also be controlled as redundant members (according to J.10) on a buckling length from leg to leg with the appropriate radius of gyration i_{yy} (see Figure J.5(g)). For the stability of the panel i_{yy} / i_w should be greater than 1,25 (i_{yy} is the radius of gyration about the axis parallel to the plane of the lattice) and the overall slenderness ratio L / i_{yy} should be less than $\boxed{350}$.

2) Furthermore the stability of the member (AB) shall be checked under the applied load on the critical buckling length L_0 for the slenderness ratio $\lambda = \boxed{1{,}0}\ L_0 / i_{vv}$.

J.6.3.7 Cross bracing with diagonal corner stays

1) In some types of cross bracing a corner stay is inserted to reduce the buckling length transverse to the plane of bracing (see Figure J.5(f)).

2) In this case five stability checks shall be carried out, to determine whether this will provide a satisfactory restraint :
   - Stability of member against the maximum load over length L_1 on the axis of the minimum inertia vv.
   - Stability of member against the maximum load over length L_2 on the transverse axis yy.
   - Stability of two members in cross brace against the algebraic sum of loads in cross brace over length L_3 on transverse axis yy.
   - Stability of two members (one in each of two adjacent faces) against the algebraic sum of the loads in the two members connected by the diagonal corner brace over length L_4 on the transverse axis yy.
   - Stability of four members (each member of cross brace in two adjacent faces) against the algebraic sum of loads in all four members over length L_5 on the transverse axis yy.

The slenderness of L_5 on transverse axis yy shall not exceed $\boxed{350}$.

J.6.3.8 K bracing : see Figure J.5 (h and i).

1) The critical buckling length is L_1 on the axis of the minimum inertia and the slenderness ratio should be taken as:

$$\lambda_1 = \boxed{1{,}0}\ L_1 / i_{vv}$$

2) Buckling over the length L_2 to the face bracing on the appropriate rectangular axis should also be checked if no hip bracing has been provided, thus the slenderness ratio should be taken as:

$$\lambda_2 = \boxed{1{,}0}\ L_2 / i_{yy} \text{ or } L_2 / i_{zz}$$

3) Where triangulated hip bracing has been provided, then the appropriate length between such hip members L_3 should be used for checking buckling transverse to the face bracing on the appropriate rectangular axis, thus the slenderness ratio should be taken as:

$$\lambda_3 = \boxed{1{,}0}\ L_3 / i_{yy} \text{ or } L_3 / i_{zz}$$

J.6.4 Compound members

J.6.4.1 General

1) Compound members may be built up with two back-to-back angle sections (Figure J.7) or with two, three or four angles in cruciform section (Figure J.8).

2) If welded continuously (Figure J.8.(a)) they may be taken as fully composite.

3) For laced compression members' reference shall be made to 5.9.2 of ENV 1993-1-1.

J.6.4.2 Details

The slenderness ratio of a sub-member shall be $\lambda_1 \leq 50$

If batten plates are adopted they shall be arranged at least at the third points of the total buckling length and at the ends of the members.
If members comprising two angle sections are connected to a common gusset plate, separate batten plates at the ends of the members are not necessary.

Every batten plate shall be connected to each sub-member by means of bolts or by an equivalent welded seam. At the ends of the members one additional connecting element shall be provided for each of these connections.
In the case of a cruciform compound member, a minimum of two bolts for each member are required at each batten plate.

J.6.4.3 Design

When the structural design complies with the requirements given previously the members may be calculated according to the following rules:

Compound members, which consist of m sub-members and have a material principal axis y-y, may be calculated against buckling transversely to this material axis as a single compression member.

As far as buckling transversely to the non-material principal axis z-z is concerned the member can be treated as a single compression member with a virtual slenderness of

$$\lambda_{zi} = \sqrt{\lambda_z^2 + \lambda_1^2 \frac{m}{2}}$$

where

m is the number of angles,

λ_z is the slenderness ratio of the full members as defined in J.6.2 or J.6.3, respectively,

λ_1 is the slenderness ratio of one sub-member and equal to c/i_{vv}

c is the distance between batten plates according to Figure J.7 and Figure J.8.

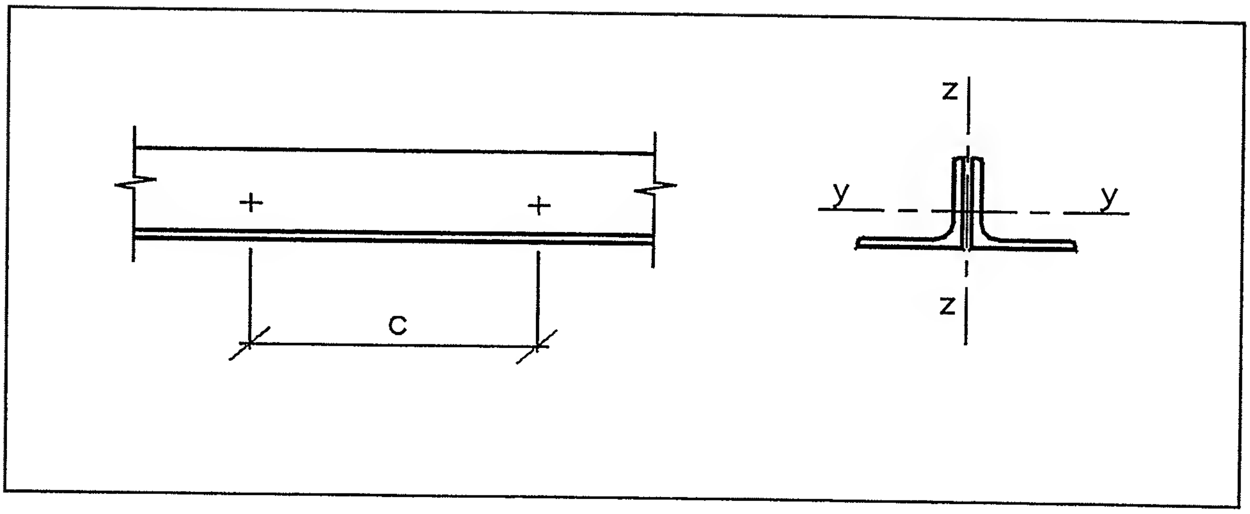


Figure J.7 - Back to back angle section

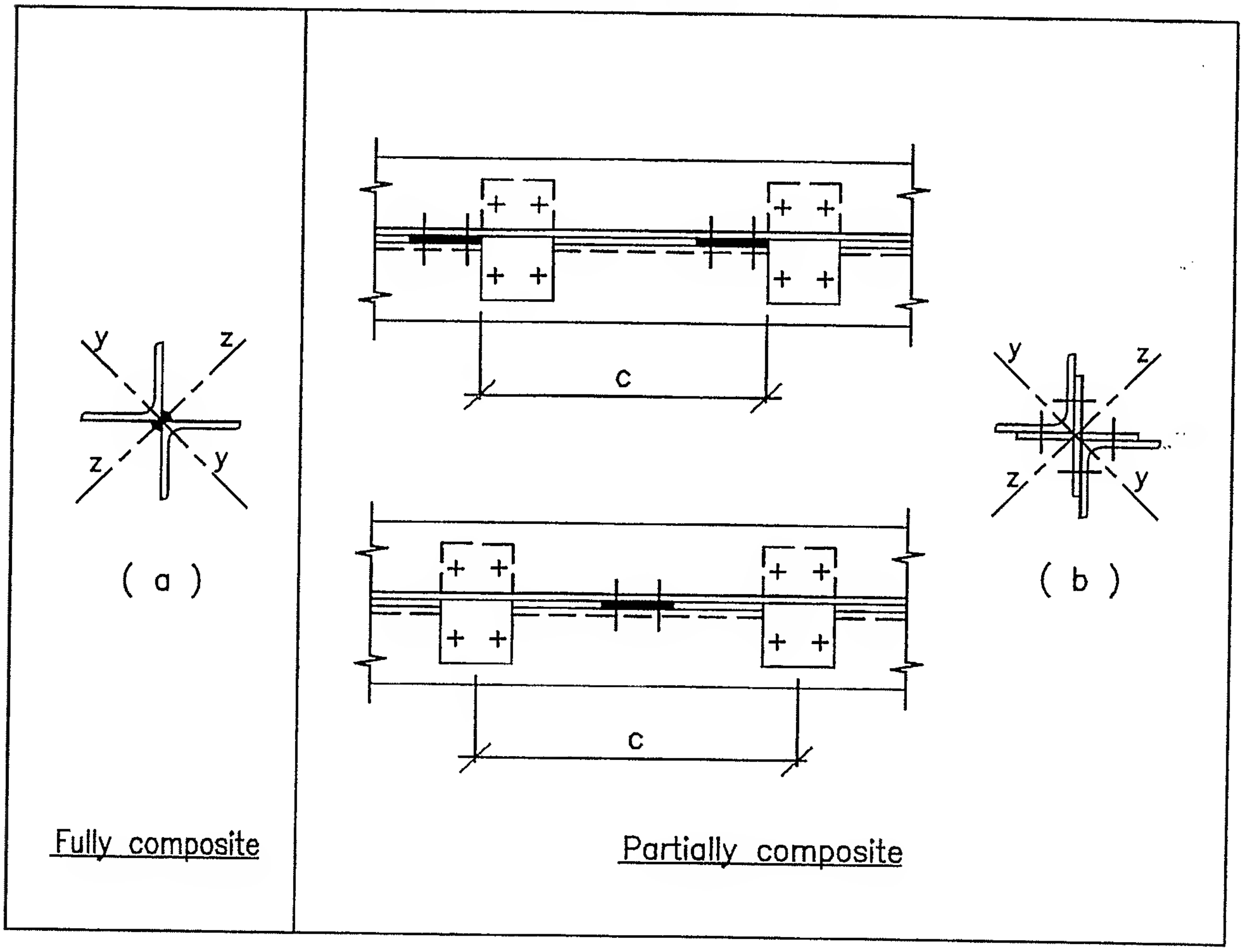


Figure J.8 - Cruciform angle sections

J.7 Additional recommendations on bracing patterns

J.7.1 Horizontal edge members with horizontal plan bracing (Figure J.9)

Due care should be taken in respect of the following :

1) Where the length of the horizontal edge members becomes large, for example when the slenderness ratio is greater than the one proposed in J.6.3.5.(3) or J.7.2.(5), or to secure the tower against partial instability, it is normal to provide a horizontal plan bracing.

2) The geometric length of the horizontal member for buckling is the distance between intersection points in the plan bracing for buckling transverse to the frame, and the distance between supports in the plane for buckling in the plane of the frame.

3) Care is needed in the choice of the vv or rectangular axes for single angle members, and the vv axis should be used unless suitable restraint by bracing is provided at or about the mid-point of the buckling length.

4) The horizontal plan bracing needs to be stiff enough to prevent partial buckling.
In case of doubt a good practice design rule is as follows :

- the horizontal plan bracing, as indicated in Figure J.9, has to resist a concentrated horizontal load F = 1,5 L, in kN, placed in the middle of the horizontal member, where: L = length of the horizontal edge member in m.
- the deflection of the horizontal bracing under this load is limited to L/1 000.

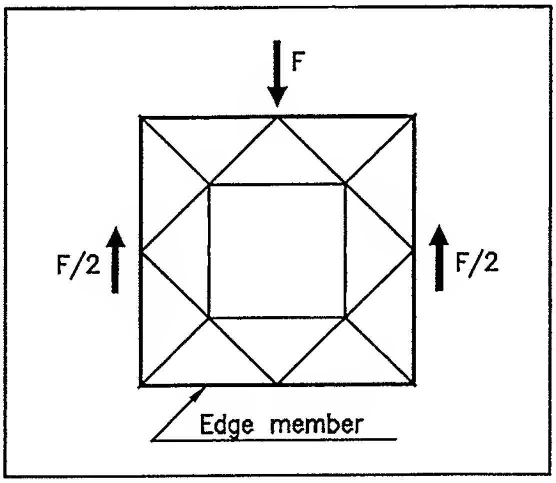


Figure J.9 - Typical plan bracing

J.7.2 Horizontal edge members without horizontal plan bracing

1) For small widths of towers and for masts, plan bracing may sometimes be omitted.

2) As the horizontal members usually have compression in one half of their length and tension in the other, the effective length kL of the horizontal transverse to the frame shall be determined from Figure J.10 depending on the ratio of the tension load, P_2, to the compression load, P_1 as given by the following formula :

$$k = 0{,}085 \times R^2 - 0{,}316\ R + 0{,}730$$

where:

$R = |P_2 / P_1|$ and $0 \leq R \leq 1$

3) The radius of gyration about the yy axis (i_{yy}) shall be used for buckling transverse to the frame except that for single angle members, either restraint by secondary bracing at intervals along the length shall be provided or the radius of gyration about the vv axis (i_{vv}) shall be used.

4) For selection of the buckling case the member shall be considered as discontinuous at both ends.

5) The overall slenderness of the horizontal edge member on the transverse axis should be less than $\boxed{250}$.

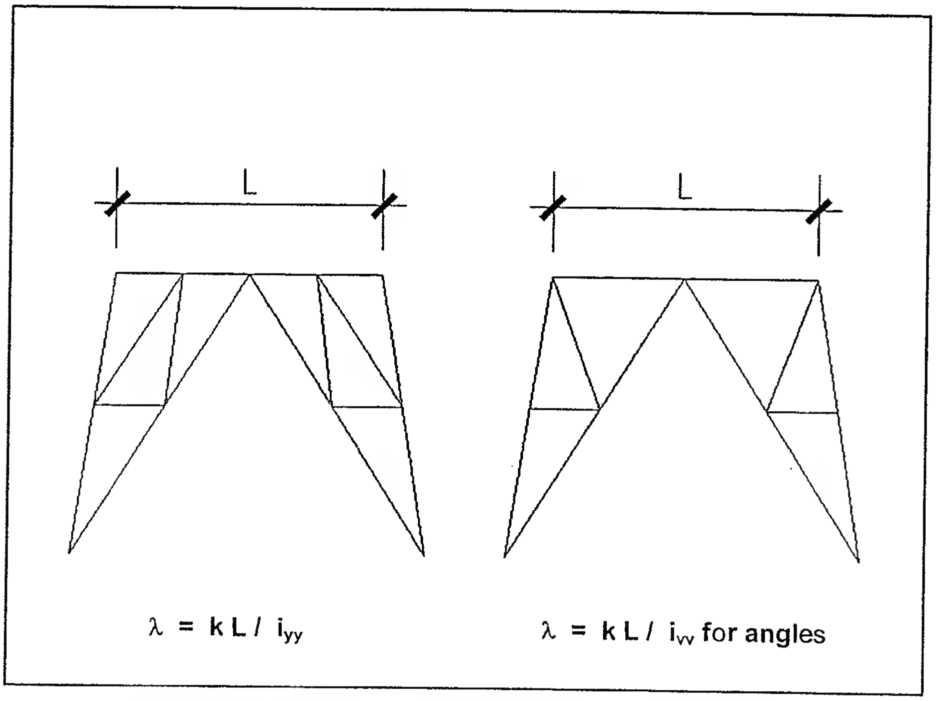


Figure J.10 - Horizontal edge member above K bracing where k = effective length factor according to J.7.2(2)

J.7.3 Cranked K bracing

For large tower widths, a bend may be introduced into the main diagonals (see Figure J.11). This has the effect of reducing the length and size of the redundant members but produces high stresses in the members meeting at the bend and necessitates transverse support at the joint. Diagonals and horizontals should be designed as for K bracing, effective lengths of diagonals being related to the lengths to the knee joint.

J.7.4 Portal frame

1) A horizontal member is sometimes introduced at the bend to turn the panel into a portal frame (see Figure J.12). The main disadvantage of this is the lack of articulation present in the K brace. This system is sensitive to foundation settlement or movement and special consideration should be given to this possibility.

2) This example also shows special secondary bracing which is less sensitive to loads resulting from such movement.

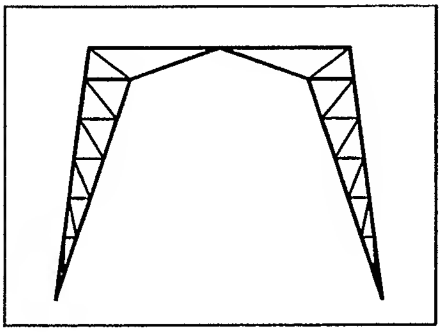


Figure J.11 - Cranked K bracing

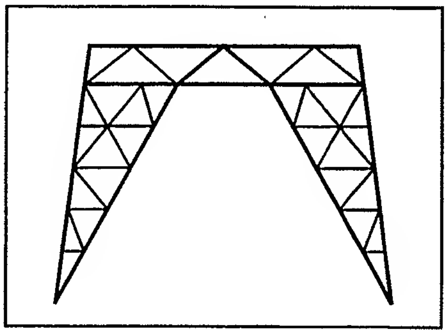


Figure J.12 - Portal frame

J.8 Calculation of effective slenderness $\bar{\lambda}_{eff}$ (design validated by tower tests)

The buckling resistance shall be determined according 5.5.1.2 of ENV 1993-1-1 with imperfection factor 0,34 (curve b).

In order to calculate the capacity of members an undimensional slenderness $\bar{\lambda}_{eff}$ is introduced, varying according to:
- type of member,
- section axis for which the strength is required,
- type of connections,
- type of bracing pattern (see J.6),
- continuity of members.

Using curve b, the $\bar{\lambda}_{eff}$ shall be calculated as follows:

$$\bar{\lambda} = \frac{\lambda}{\pi}\sqrt{\frac{f_y}{E}\frac{A_{eff}}{A}}$$

Case 1	$\bar{\lambda}_{eff} = e^{(1,747\,\bar{\lambda} - 1,98)}$	for $0,2 < \bar{\lambda} < 1,035$
	$\bar{\lambda}_{eff} = 1,091 \,.\, \bar{\lambda} - 0,287$	for $\bar{\lambda} > 1,035$
Case 2	$\bar{\lambda}_{eff}$ = as case 1 with $\bar{\lambda} = \boxed{1,2}$ times $\bar{\lambda}$ of case 1	
Case 3	$\bar{\lambda}_{eff} = 0,02 + 0,88\,\bar{\lambda}$	
Case 4	$\bar{\lambda}_{eff} = 0,30 + 0,68\,\bar{\lambda}$	
Case 5	$\bar{\lambda}_{eff} = 0,52 + 0,68\,\bar{\lambda}$	
Case 6	$\bar{\lambda}_{eff} = 0,16 + 0,94\,\bar{\lambda}$	

The appropriate buckling case shall be selected from J.9 (Table J.1).

J.9 Selection of buckling cases for angles (design validated by tower tests)

J.9.1 Single angle

1) The basic buckling curve is the curve b of ENV 1993-1-1.

2) For leg members, two cases are foreseen.
The case 1 refers to an axially loaded strut, continuous through a number of panels, with supports not staggered, as Figure J.3 (a), (b) and (c).
The case 2 refers to the same strut with staggered supports, as Figure J.3 (d).

3) For bracing members the following considerations apply.
The end connections of bracing members connected by one leg produce eccentricities and/or restraints, both of which affect the carrying capacity of the members.
As the slenderness ratio increases, so the effect of the eccentricity diminishes and the beneficial effect of the fixity of the ends increases, so that for calculation purposes it should be assumed that these effects shall cancel each other out at a slenderness parameter value of $\lambda = \sqrt{2}$.
At lower slenderness ratios, the resistance of the connection normally governs the capacity of single bolted members.
For higher slenderness ratios, the beneficial effect of end restraints becomes more important than the negative one due to the eccentricity of the connection, thus enabling a better case to be used where suitable end fixity exists (minimum 2 bolts, or welded connection or rigidity of the restraining angle).

4) In all cases buckling lengths are the geometrical ones, i.e. distance between centre line intersections.

5) The appropriate case is determined from Table J.1; member continuity conditions are:

2 ends	=	the member is continuous at both ends;
1 end	=	the member is continuous at one end only;
0 end	=	single span member.

6) A bracing member fixed to both legs is considered as a leg member.

7) A bracing member fixed by welding is considered as connected by two bolts.

J.9.2 Compound members / Laced members

All cases are treated as case 1 for the overall check of the compound member.
The single member shall be checked according to Table J.1.

Table J. 1 - Buckling cases

	Buckling axis	Slenderness condition $\bar{\lambda}$	Load eccentricity condition	Member continuity condition	Number of bolts at non-continuous end	No. case
Bracing member	VV	$< \sqrt{2}$	1 end	-	-	3
		$< \sqrt{2}$	2 ends	-	-	4
		$> \sqrt{2}$	-	2 ends	-	1
		$> \sqrt{2}$	-	1 end	2 bolts	4
		$> \sqrt{2}$	-	1 end	1 bolt	1
		$> \sqrt{2}$	-	0 end	2 bolts	4
		$> \sqrt{2}$	-	0 end	1 bolt	1
	YY or ZZ	$< \sqrt{2}$	1 end	-	-	4
		$< \sqrt{2}$	2 ends	-	-	5
		$> \sqrt{2}$	-	2 ends	-	1
		$> \sqrt{2}$	-	1 end	2 bolts	4
		$> \sqrt{2}$	-	1 end	1 bolt	1
		$> \sqrt{2}$	-	0 end	2 bolts	5
		$> \sqrt{2}$	-	0 end	1 bolt	6
Leg member	VV	all cases	Figure J.3 (a) (b)			1
	YY or ZZ	all cases	Figure J.3 (c)			1
		all cases	Figure J.3 (d) (staggered)			2

J.10 Secondary (redundant) members

1) In order to design secondary members it is necessary to introduce a hypothetical force transverse to the main member being stabilised, at each node point of the attachment of the secondary member. These loads are not additive to the existing forces on the structure.
This force is applied at each node in turn in the plane of the bracing and its value is calculated equal to : $\frac{K.N}{100}$
where:

K $= \frac{1}{60}(\lambda + 32)$ with $1 \leq K \leq 2$

N is the axial force in the main member

2) The angle between the redundant and the main member shall be not less than 15°.

3) In case of cranked K bracing (Figure J.11) with angle between diagonal and main leg close to 15°, secondary effects should be taken into consideration (global instability, main leg shortening, bolt slip).

J.11 Bolted connections

Bolted connections for angle members shall be designed in accordance with Table J.2 and Figure J.13.

Table J.2 - Design resistance for bolts in angle

<u>Shear resistance per shear plane</u>: If the shear plane passes through the unthreaded portion of the bolt: $F_{v,Rd} = \dfrac{\boxed{0{,}6}\ f_{ub}\ A}{\gamma_{Mb}}$ If the shear plane passes through the threaded portion of the bolt $F_{v,Rd} = \boxed{0{,}6}\ f_{ub}\ A_s/\gamma_{Mb}$ for classes 4.6 - 5.6 - 6.6 - 8.8 $F_{v,Rd} = \boxed{0{,}5}\ f_{ub}\ A_s/\gamma_{Mb}$ for classes 4.8 - 5.8 - 6.8 - 10.9
<u>Bearing resistance per bolt</u> : $F_{b,Rd} = \dfrac{\alpha\ f_u\ d\ t}{\gamma_{M2}}$ where α is the smallest of: 1,20 (e_1/d_o); 1,85 $(e_1/d_o - 0{,}5)$; 0,96 $(P_1/d_o - 0{,}5)$; 2,3 $(e_2/d_o - 0{,}5)$
<u>Tension resistance per bolt</u> : $F_{t,Rd} = \dfrac{0{,}9\ f_{ub}\ A_s}{\gamma_{Mb}}$
A is the cross-section area of bolt A_s is the tensile stress area of bolt d is the bolt diameter d_0 is the hole diameter

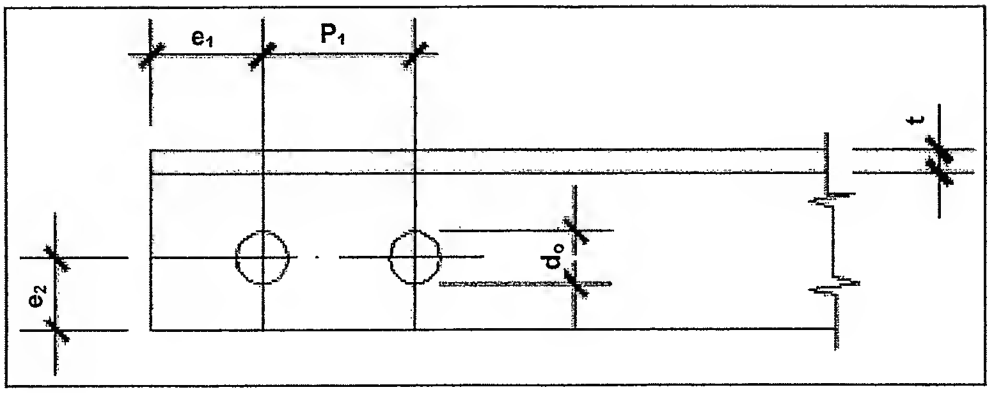


Figure J.13 - Location of bolts in angle member connected by one leg

Annex K
(normative)

Steel poles

In the following clauses reference is made to the corresponding chapters of ENV 1993-1-1 in brackets.

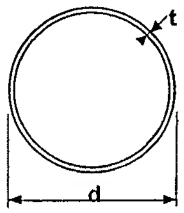
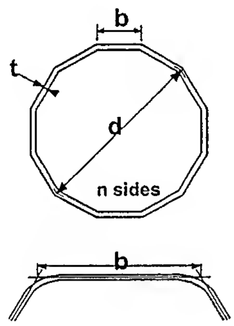
K.1 Definition of symbols used in this annex

Symbol	Signification
A	Cross section area
A_{eff}	Effective cross section area
A_s	Tensile stress area of holding-down bolt
b	Nominal width
b_{eff}	Effective width
d	Outside diameter ; outside diameter across angles of polygon
f_{bd}	Bonding stress of steel into concrete
f_{ck}	Characteristic strength of concrete in compression
f_{ctm}	Average strength of concrete in tension
$f_{ctk0,05}$	Characteristic strength of concrete in tension
f_{ub}	Ultimate tensile strength for holding-down bolt
f_y	Yield strength
M_{sd}	Bending moment at cross section
N_{sd}	Axial force at cross section
n	Number of sides of the polygon
t	Thickness
W_{eff}	Effective cross section modulus
W_{el}	Elastic section modulus
ΔM	Additional moment
$\sigma_{com,Ed}$	Maximum calculated compressive stress
$\sigma_{x,Ed}$	Actual maximal longitudinal stress
γ_c	Partial safety factor on bonding
γ_{M1}	Partial safety factor for resistance
γ_{Mb}	Partial safety factor for resistance of holding-down bolt
$\overline{\lambda}_p$	Plate slenderness
ρ	Reduction factor
ψ	Stress ratio

K.2 Classification of cross sections (Chapter 5.3)

Cross sections shall be considered as class 3 if the thinness of the wall allows the calculated stress in the extreme compression fibre of the tube to reach its yield strength. All other sections, in which it is necessary to make explicit allowances for the effects of local buckling when determining their moment resistance or compression resistance, shall be considered as class 4 according to the criteria given in Table K.1.

Table K.1 - Classification of tubular cross sections in bending

Type of section	**Criteria for class 4**
	$d/t > 176\ \varepsilon^2$
	for n equal 6 to 18 sides $b/t > 42\ \varepsilon$
where $\varepsilon = (235/f_y)^{0,5}$ and f_y is the nominal value of the yield strength in N/mm^2	

K.3 Effective cross-sections properties of class 4 cross-sections (Chapter 5.3.5)

The effective cross-section properties of Class 4 cross-sections shall be based on the effective widths (areas in black) of the compression elements as shown in Figure K.1.

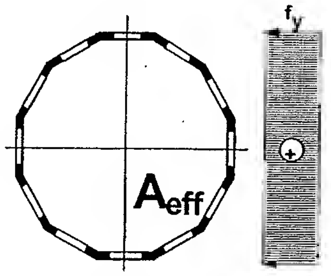
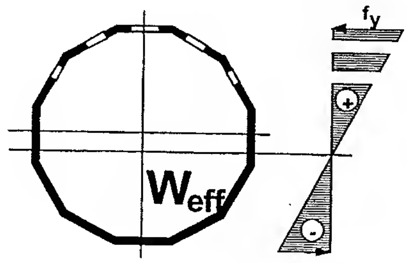
A_{eff} under axial force	*W_{eff} under bending moment*
	

Figure K.1 - Class 4 effective cross-sections characteristics

The effective widths of flat compression internal elements should be designed using Table 5.3.2 of ENV 1993-1-1, where as a safety approximation, the reduction factor ρ may be obtained from 5.3.5 (3) of ENV 1993-1-1. The stress ratio ψ used in Table 5.3.2 of ENV 1993-1-1 may be based on the properties of the gross cross-section.

However, for greater economy, the plate slenderness $\bar{\lambda}_p$ of each element may be determined using the maximum calculated compressive stress $\sigma_{com,Ed}$ in that element in place of the yield strength f_y, provided that $\sigma_{com,Ed}$ is determined using the effective widths b_{eff} of all the compression elements. This procedure generally requires an iterative calculation in which ψ is determined again at each step from the stresses calculated on the effective cross-section defined at the end of the previous step, including the stresses from the additional moment ΔM.

K.4 Resistance of circular cross sections, without opening, under preponderant bending moment

The resistance of a circular cross section, without opening, under preponderant bending moment is ensured if the actual maximal longitudinal stress $\sigma_{x,Ed}$ (including the simultaneous axial force), calculated on the gross section, satisfies the following criteria :

$$\sigma_{x,Ed} \leq \rho . f_y / \gamma_{M1}$$

with: for class 3 sections : $\rho = 1{,}0$

for class 4 sections : $\rho = 0{,}70 + \dfrac{53\varepsilon^2}{d/t} \leq 1{,}0$, with $\varepsilon = \left(235/f_y\right)^{0{,}5}$

Figure K.2 gives directly the reduction factor ρ as a function of the ratio *d/t* .

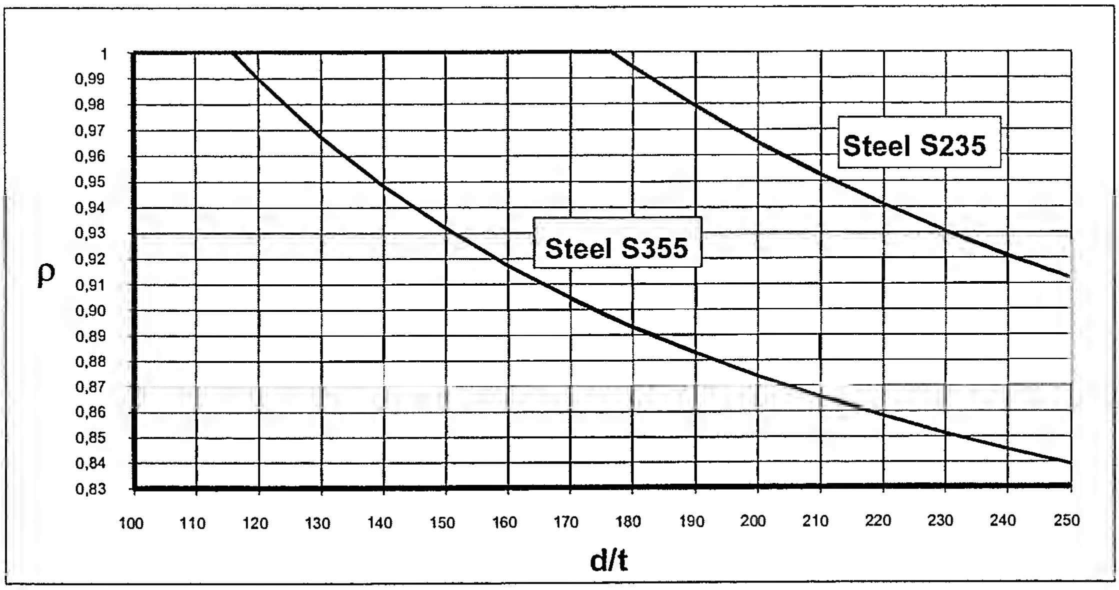


Figure K.2 - Reduction factor ρ

K.5 Resistance of polygonal cross sections, without opening, under preponderant bending moment

K.5.1 Class 3 cross-sections (Chapter 5.4.8.2)

The resistance of a class 3 polygonal cross section will be satisfactory if the maximum longitudinal stress $\sigma_{x,\,Ed}$, calculated on the gross section, under preponderant bending moment and simultaneous axial force, satisfies the criterion:

$$\sigma_{x,Ed} \leq f_y / \gamma_{M1}$$

For cross sections without opening the above criterion becomes:

$$\frac{N_{Sd}}{A} + \frac{M_{Sd}}{W_{el}} \leq \frac{f_y}{\gamma_{M1}}$$

where:

A	is	the gross cross-section area
W_{el}	is	the elastic section modulus

K.5.2 Class 4 cross-sections (Chapter 5.4.8.3)

Class 4 polygonal cross section, without opening, will be satisfactory if the maximum longitudinal stress $\sigma_{x,\ Ed}$, calculated on the effective widths of the compression elements, under preponderant bending moment and simultaneous axial force, satisfies the criterion:

$$\sigma_{x,Ed} \leq f_y / \gamma_{M1}$$

For cross sections without opening the above criterion becomes:

$$\frac{N_{Sd}}{A_{eff}} + \frac{M_{Sd}}{W_{eff}} \leq \frac{f_y}{\gamma_{M1}}$$

where:

A_{eff} is the effective area of the cross-section when subject to uniform compression.

W_{eff} is the effective section modulus of the cross-section when subject only to moment about the relevant axis.

NOTE The detailed method for calculation of effective cross-section properties of Class 4 cross-sections is given in 5.3.5 of ENV 1993-1-1. The monograms of Figures K.3 and K.4 allow a quick determination of A_{eff} and W_{eff} for polygonal cross section, without opening.

K.6 Design of holding-down bolts

The design of the anchorage length of holding-down bolts into concrete is given in Table K.2. Combined design resistance of bolts in shear and tension or compression is given in 6.5.5 of ENV 1993-1-1.

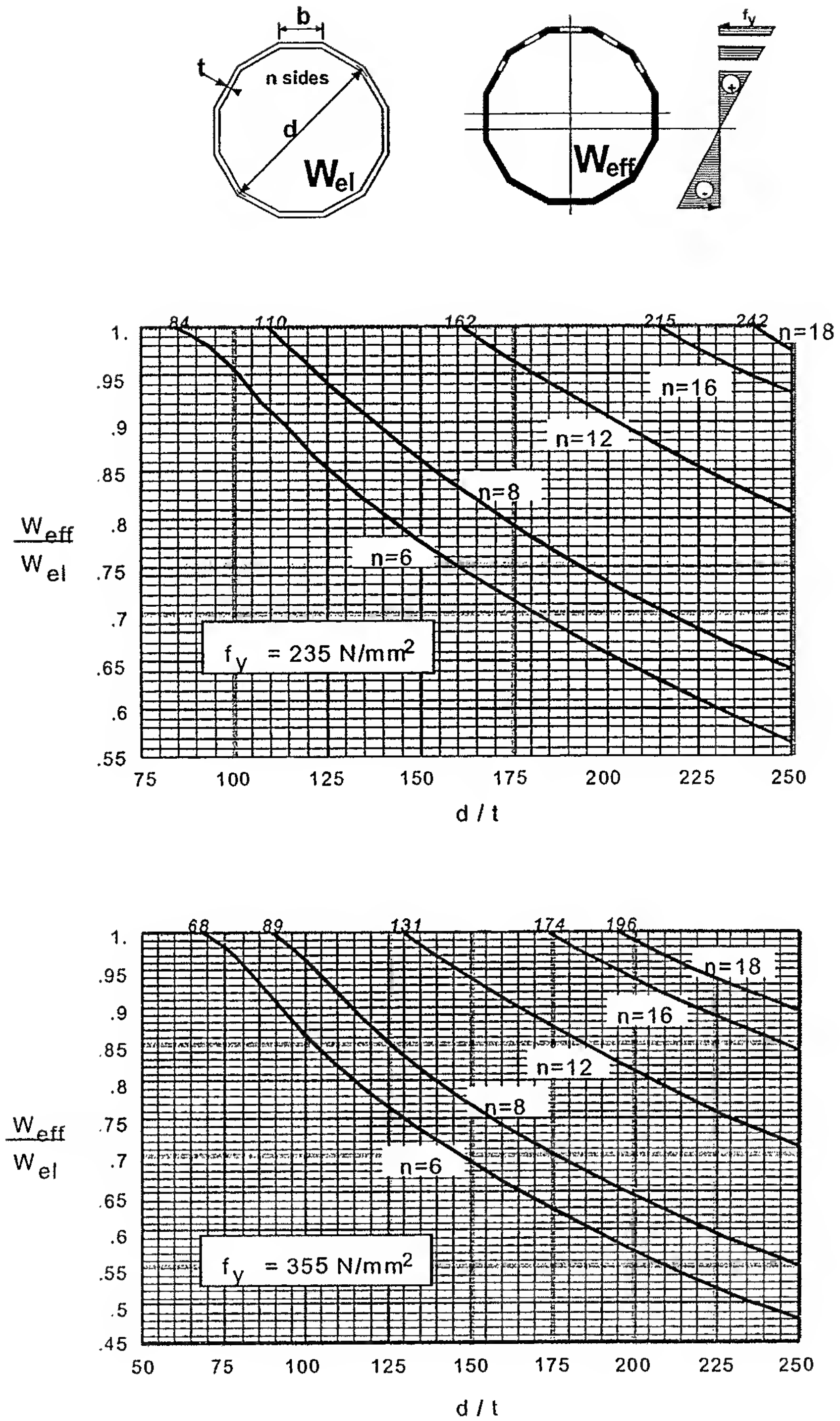
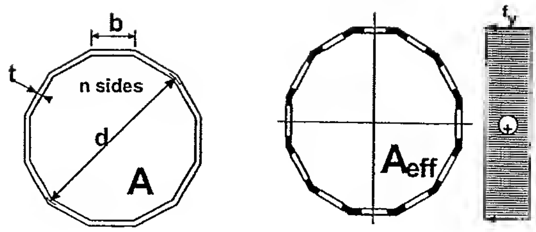
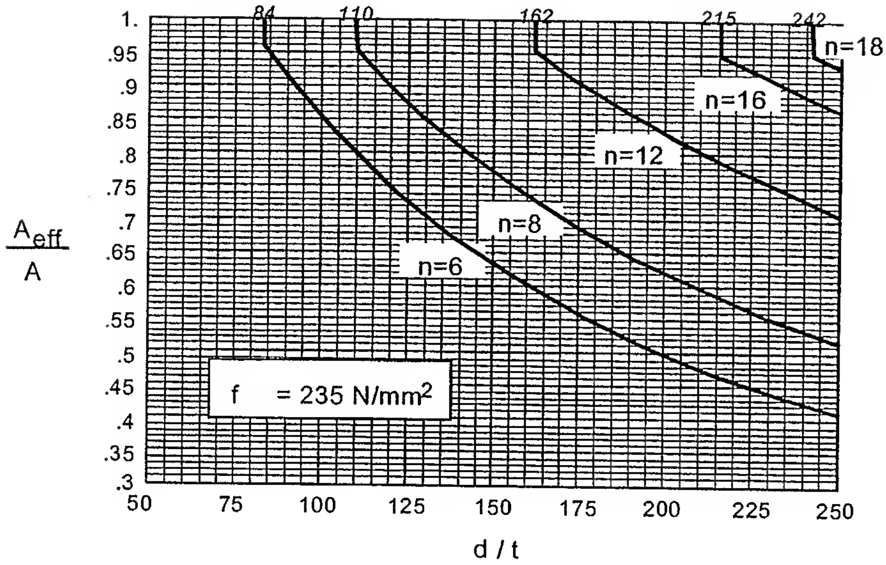


Figure K.3 - Class 4 polygonal cross-sections

Effective section modulus W_{eff}





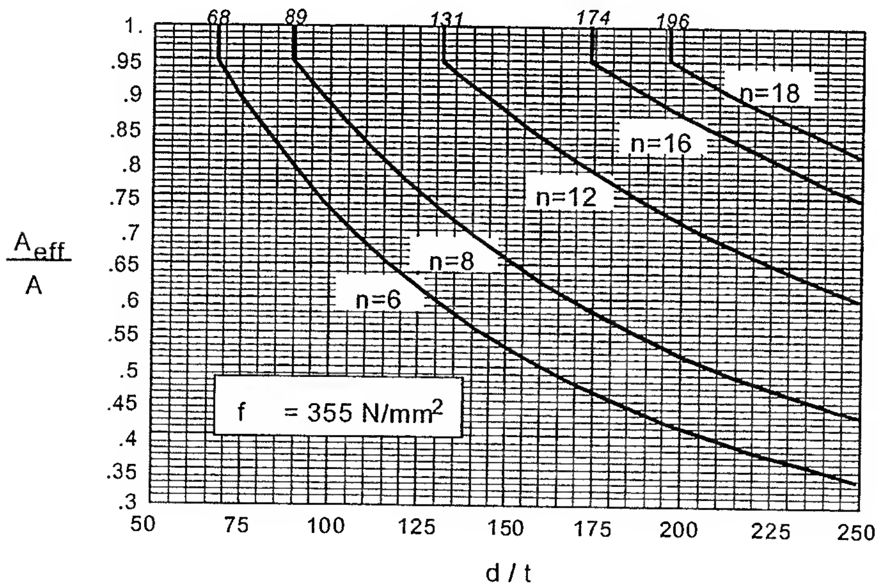
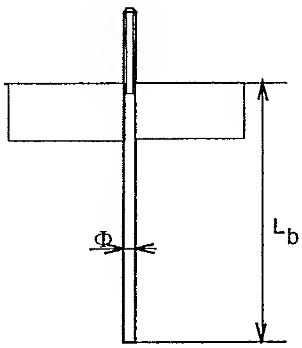
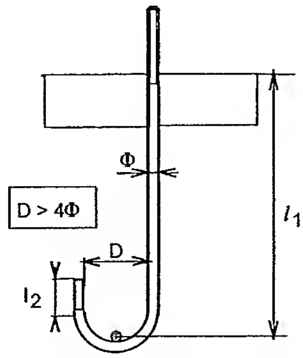
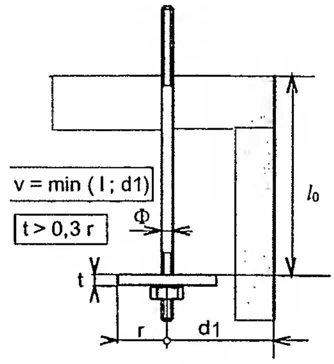


Figure K.4 - Class 4 polygonal cross-sections

Effective area A_{eff}

Table K.2 - Design of holding-down bolts

<table>
<tr><th>Straight anchor</th><th>Anchor with bend</th><th>Anchor with plate</th></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
<tr><td>$F_{a,Rd} = \pi.\Phi L_b.f_{bd}$</td><td>$F_{a,Rd} = \pi.\Phi.L_b.f_{bd}$
with
$L_b = (l_1 + 3{,}2D + 3{,}5l_2)$</td><td>$F_{a,Rd} = \pi.\Phi.L_b.f_{bd}$
with
$L_b = 2{,}45\Phi \frac{f_{cd}}{f_{bd}}\left(\frac{r^2}{\Phi^2} - 0{,}25\right)\left(1 - \frac{r}{v}\right) + l_0$</td></tr>
<tr><td colspan="3">f_{bd} = bonding stress of steel into concrete
with : $f_{bd} = \frac{0{,}36\sqrt{f_{ck}}}{\gamma_c}$ for plain bars and $f_{bd} = \frac{2{,}25 f_{ctk0{,}05}}{\gamma_c}$ for deformed bars
with : $f_{ctk0{,}05} = 0{,}7 f_{ctm}$ and $f_{ctm} = 0{,}3 f_{ck}^{2/3}$
where f_{ck} = characteristic strength of concrete in compression
f_{ctm} = average strength of concrete in tension
$f_{ctk0{,}05}$ = characteristic strength of concrete in tension
γ_c = partial safety factor on bonding $\boxed{1{,}50}$
=
for example : with C 20/25 concrete f_{ck} = 20 N/mm², f_{ctm} = 2,2 N/mm², $f_{ctk0.05}$ = 1,55 N/mm²,
and f_{bd} = 1,1 N/mm² for plain bars or f_{bd} = 2,3 N/mm² for deformed bars</td></tr>
<tr><td colspan="3">The anchoring length shall be such that : $F_{a,Rd} = \pi.\Phi.L_b.f_{bd} \geq F_{t,Sd}$
where $F_{t,Sd}$ = design tensile force per bolt for the ultimate limit state</td></tr>
<tr><td colspan="3">The size of the bolt shall be such that : $F_{t,Sd} \leq F_{t,Rd} = 0{,}9.f_{ub}.A_s./\gamma_{Mb}$
where : f_{ub} = ultimate tensile strength of holding-down bolt
A_s = tensile stress area of holding-down bolt
γ_{Mb} = partial safety factor on resistance of holding-down bolt = $\boxed{1{,}25}$
NOTE According to 6.5.5 (6) of ENV 1993-1-1, when threads are cut by a non-specialist bolt manufacturer, the relevant value of $F_{t,Rd}$ shall be reduced by multiplying it by a factor of 0,85</td></tr>
</table>

Annex L
(informative)

Design requirements for supports and foundations

L.1 Structural requirement

The following information is required for the design of supports and foundations :

— applied loads, including partial coefficients for actions, at attachment point of insulators/conductors/ earth-wires (in the form of the arrangement of transverse (T), vertical (V) and longitudinal (L) loads);
— wind loads on supports;
— load combinations;
— ultimate limit state for each load combination;
— serviceability limit state for each load combination (allowable deflections);
— preferred failure sequence;
— maintenance and construction loadings.

L.2 Configuration requirements : types of supports and uses

The support type, outline, disposition of phase conductors, interphase spacing, electrical clearances and disposition of earthwires should be as specified in the Project Specification.

The following tables may be used as a guide.

Table L.1 - Support type and use

Support Type	Description	Angles of deviation or line entry	Type of insulator
......	......	......	......

Table L.2 - Range of extensions

Support type	Range of extension	Description
	Minimum height Maximum height x incremental extension (metres)	
......	......	......

NOTE It should be stated in the description column whether extensions are either individual extensions or combinations of body and leg extensions. The latter height of body extension and range of leg extensions should be stated. In addition, limitations of use, interchangeability, connection levels and maximum permitted height differences between individual leg extensions should be clearly stated

Table L.3 - Line design particulars

Number of sub-conductors per phase
Size and type of sub-conductors
Arrangement of sub-conductors
Spacing of sub-conductors (horizontally and vertically)
Number and type of earth conductors
Size of earth conductors
Standard span length for standard height support
Standard height support
Maximum earthwire shielding angle of top/outside
Phase conductor, still air (degrees)
Maximum single span length
Maximum sum of adjacent span lengths
Maximum weight span, normal conditions
Maximum weight span, unbalanced conditions
Minimum weight span under normal conditions with max. wind span
Minimum weight span, unbalanced conditions
Maximum weight span, for terminal supports

Table L.4 - Insulator string details

Minimum/maximum insulator set lengths Suspension set Post insulator set Pilot suspension set Tension set inner string Tension set outer string Low duty set, with or without adjustment Number of strings per phase Suspension Tension Low duty Minimum clearance from live metal to support steel or earthed fittings Assumed maximum swing of suspension set (degrees) Suspension insulator strings: (a) Inclined between 0 and .... degrees from vertical (b) Inclined between .... and maximum from vertical Tension insulator string: (a) Jumper loop hanging vertically (b) Jumper loop inclined .... degrees from vertical Weighted pilot suspension string : (a) Assumed initial deflection under still air conditions .... degrees (b) Maximum deflection .... degrees with jumper at maximum deflected position
NOTE 1 Where possible, drawing of insutator set should be provided, complete with arcing devices, sag adjustment and support attachment details. NOTE 2 If V-strings are used, length of string between attachments or included angle and whether the V-string is capable of withstanding compressive loading should be specified. If post insulators are used, inclination of post to the horizontal should be specified.

Table L.5 - Spatial distance

Arrangement of phase conductors, vertical
Arrangement of phase conductors, horizontal
Arrangement of phase conductors, delta
Minimum height of phase conductors at the support on standard height ... type supports
Maximum swing of earth conductors from vertical (degrees)
Minimum vertical spacing between adjacent phase conductors of one circuit
Minimum projected horizontal spacing between adjacent phase conductors of one circuit
Minimum vertical spacing between phase and earth conductors

L.3 Phase conductor and earthwire attachment

Details of the phase conductor and earthwire insulator attachments to the support crossarms/body should be as stated in the Project Specification or agreed with the client prior to detail design commencing.

L.4 Foundation steelwork

Details of the proposed method of interconnection between the support and the foundation, e.g. stubs and cleats, anchor bolts or embedded sections should be as stated in the Project Specification or agreed with the client.

L.5 Erection/maintenance facilities

Provision of erection and subsequent maintenance facilities, which have design implications, should be clearly stated in the Project Specification or in accordance with 7.12 of this standard, e.g:

— provision for maintenance facilities ;
— provision for attachment facilities ;
— provision for terrain circumstances in respect to erection ;
— provision for transportation possibilities ;
— provision for marking facilities ;
— provision for grounding requirements.

L.6 Mass-length restrictions

Any special restrictions on either the overall support configuration or fabrication process, which have design implications, should be clearly stated in the Project Specification, e.g :

— restrictions on overall base width of support ;
— restrictions on overall dimensions of panels ;
— restrictions on overall dimensions or masses of individual members ;
— restrictions on site welding ;
— restrictions on proposed erection methods.

Annex M
(informative)

Typical values of the geotechnical parameters of soils and rocks

M.1 General

The values of the geotechnical parameters given hereafter should be used when results of a geotechnical investigation are not available. They should not take the place of a soil investigation, and the values quoted should be confirmed during construction.

If any doubt arises as to the assignment of a given soil to one of the categories appearing in the following tables, the more pessimistic value should be adopted.

In Table M.1, some of the most commonly encountered soils are described according to their origin and evaluated as to their suitability as a foundation layer.

The next two Tables M.2 and M.3 give, for the main categories, cohesive and non cohesive soils and rocks, the ranges of values of geotechnical parameters needed for the foundation design formulae.

M.2 Definitions

Soil classification according to particle size

Particle size in mm			Definition
	d >	200	Boulders
200	> d >	20	Pebbles, Cobbles
20	> d >	2	Gravel
2	> d >	0,2	Sand (coarse)
0,2	> d >	0,06	Sand (fine)
0,06	> d >	0,002	Silt
	d <	0,002	Clay

M.3 Units

γ	:	Specific weight,	kN/m^3
γ'	:	Specific weight under buoyancy,	kN/m^3
Φ'	:	Angle of internal friction	degree
c'	:	Cohesion (effective),	kN/m^2
c_u	:	Undrained shear strength,	kN/m^2
C_t	:	Subgrade modulus at 2 m depth,	MN/m^3
R_C	:	Crushing strength,	MN/m^2
R_t	:	Tensile strength,	MN/m^2
E	:	Young's modulus,	MN/m^2

Table M.1 - Commonly encountered soils

	Soil type	Mode of formation	Description	Technical features and aptitude as foundation course
1	**Lateral moraine, gravelly**	Sandy-gravelly deposit of glacial origin, deposited at the edge of the glacier	Sandy-gravelly material, with a wide range of particle sizes. Very heterogeneous	Medium to high compacity, low compressibility, pervious. Very good foundation layer.
2	**Glacial till (unsorted)**	Unsorted glacial deposit from clay to gravel, usually in dense state. Usually covers molassic layers or bedrock.	Gravelly material in a silty-clayey matrix, with wide range of particle sizes.	High compaction, low compressibility, impervious. Good foundation layer.
3	**Glacial drift, sorted by rivers**	Sandy-gravelly layer from morainic aluvium	Sandy-gravelly material, without large pebbles, and clay, with little silt	Mean compaction, mean to high compressibility, pervious. Good foundation layer.
4	**Glacial clay**	Very fine grained material from morainic eluvion and deposited in lakes	Varied clays with layers of silt and fine sands. Possible presence of peat and mud	Low compaction, medium to high plasticity, compressible, impervious. Poor foundation soil.
5	**Alluvial soil**	Deposits in flood plains and estuaries.	Alternances of silty-sandy and gravelly deposits. Possible presence of peat and mud	Variable compaction and permeability, inhomogeneous soil. Poor to good foundation soil.
6	**Boulders**	Boulders heap at the toe of a cliff	Detached angular rock fragments of varying sizes	Low compaction, high permeability. Acceptable for foundations, although unstable.
7	**Overconsolidated soils**	Sedimentary soils subjected to greater overburden than at present.	Clays Sands Silts	Generally acceptable for foundations.
8	**Soft rocks (weathered to un-weathered)**	Sedimentary soils etc. subjected to greater overburden pressure than overconsolidated soils.	Mud-stone (incl. Marl) Sandstone Chalk	Weathered rocks should be evaluated from case to case. Otherwise generally good for foundations.

Table M.2 - Geotechnical characteristics of some standard soils
(Definitions as given in clauses M.2 and M.3)

Soil	γ kN/m³	γ' kN/m³	Φ' degree	c' kN/m²	c_u kN/m²	Ct MN/m³
Marl, compact	20 ± 2	11 ± 2	25 ± 5	30 ± 5	60 ± 20	> 200
Marl, altered	19 ± 2	11 ± 2	20 ± 5	10 ± 5	30 ± 10	50 ± 10
Gravel, graded	19 ± 2	10 ± 2	38 ± 5	-	-	150 ± 10
Sand { loose	18 ± 2	10 ± 2	30 ± 5	-	-	60 ± 10
Sand { semi-dense	19 ± 2	11 ± 2	32 ± 5	-	-	80 ± 10
Sand { dense	20 ± 2	12 ± 2	35 ± 5	-	-	100 ± 10
Sandy silt	18 ± 2	10 ± 2	25 ± 5	10 ± 5	30 ± 10	60 ± 10
Clayey silt	19 ± 2	11 ± 2	20 ± 5	20 ±10	40 ± 10	50 ± 10
Loam, Silt, malleable	17 ± 2	7 ± 2	20 ± 5	-	20 ± 10	35 ± 5
Clay { soft	17 ± 2	7 ± 2	12 ± 5	25 ± 5	60 ± 20	25 ± 5
Clay { semi-stiff	19 ± 2	9 ± 2	15 ± 5	25 ± 5	60 ± 20	30 ± 5
Clay { stiff	20 ± 2	10 ± 2	20 ± 5	25 ± 5	60 ± 20	40 ± 5
Clay Till	20 ± 2	10 ± 2	30 ± 5	12 ± 7	400 ± 350	-
Clay, with organic addition	15 ± 2	5 ± 2	15 ± 5	-	-	-
Peat, Marsh	12 ± 2	2 ± 2	-	-	-	-
Backfill, Embankment, medium compaction	19 ± 2	10 ± 2	25 ± 5	-	15 ± 5	20 ± 5

Table M.3 - Mechanical properties of some common rocks
(Definitions as given in clauses M.2 and M.3)

Rock designation	Rc MN/m²	Rt MN/m²	E MN/m²
Granite-Gneiss- Basalt	100 - 200	4 -10	20 000 - 70 000
Clay - Shale	15 - 100	0 - 10	7 000 - 50 000
Limestone, compact	50 - 100	5 - 7	30 000 - 60 000
Limestone, soft	10 - 20	1 - 3	4 000 - 20 000
Marl, not altered	10 -20	1 - 2	200 - 1 000
Sandstone	10 - 100	1 - 6	10 000 - 40 000
Molasse	2 - 10	0,2 - 1	1 500 - 5 000
Gypsum	3 - 10	0,3 - 1	2 000 - 5 000

NOTE - Poisson's coefficient μ lies generally between 0,25 and 0,35.
- The angle of internal friction Φ' lies generally between 35° and 45° and is strongly dependent upon the degree and the direction of fissuration.

Annex N
(informative)

Conductors and overhead earthwires

N.1 Specification of conductors and earthwires

N.1.1 Factors influencing the specification of conductors and earthwires

Conductors and earthwires for use in the construction of an overhead line are designed to meet the relevant mechanical and electrical characteristics as determined by the design parameters for the line. Additional factors relating to operation, maintenance and the environmental impact may need to be considered when specifying the requirements for conductors and earthwires for use in the construction of the line.

N.1.2 Operational factors

Typical factors involved are:

— target system reliability and line restoration time for different categories of forced outage;
— current carrying capabilities (continuous and short-term);
— constraints on electrical losses (I^2R and corona);
— internal and external clearances;
— constraints on line electrical characteristics (series reactances, shunt susceptances etc);
— required lifetime.

N.1.3 Maintenance requirements

An important requirement involved is:

— access along conductors to in-span fittings (e.g. spacers and visibility markers).

N.1.4 Environmental parameters

Typical parameters involved are:

— wind and/or ice loadings affecting strength selection, conductor sag, vibration and galloping performance;
— pollution - affecting corrosion protection;
— lightning - affecting earthwire and conductor specification;
— radio (and other) interference constraints;
— audible noise constraints;
— visibility marking for birds and aircraft
— visual amenity (e.g. surface finish of conductors);
— electric and magnetic fields;
— conductor grease (e.g. drop point and chemical content);
— maximum and minimum ambient temperatures.

N.2 Selection of conductors and earthwires

In addition to the specified characteristics on the basis of the overhead line design parameters, and the factors detailed in N.1, consideration should also be given to the choice of conductors for particular applications.

This consideration may include:

- conductor type - round wire, segmental, stranded or other constructions;
- bundle type - single conductor, twin, triple, quad etc.;
- conductor material of which examples are:
  a) all aluminium conductor (AL1);
  b) aluminium conductor aluminium alloy reinforced (AL1/ALx);
  c) aluminium conductor steel reinforced (AL1/STyz);
  d) aluminium conductor aluminium clad steel reinforced (AL1/SAyz);
  e) aluminium alloy conductor steel reinforced (ALx/STyz);
  f) aluminium alloy conductor aluminium clad steel reinforced (ALx/SAyz);
  g) all aluminium alloy conductor (ALx);
  h) aluminium clad steel conductor (20SA);
  i) copper/copper alloy;
  j) steel.
- conductor and bundle dimensions;
- current carrying capabilities;
- grease type and content;
- surface finish (including painting);
- conductivity;
- stress/strain behaviour;
- tensile strength (including reduction with temperature and time);
- creep;
- optical fibre requirements (including protection);
- corrosion protection;
- vibration characteristics (self damping, vertical and rotational stiffness, mass/length etc.);
- maximum operating temperature (continuous, short-duration, and short-circuit);
- permitted overhead line support loadings.

N.3 Packing and delivery of conductors and earthwires

Conductors should be packed and delivered to site on suitable drums containing lengths previously agreed between the purchaser and supplier; the treatment for wooden drums should be specified in the Project Specification. The drums should give adequate protection to the conductors. Suitable arrangements should be made for the return or disposal of empty drums.

N.4 Precautions during installation of conductors and earthwires

At all times during installation conductors should be handled with care to minimise surface damage. In particular precautions should be taken to avoid abrasive contact with the ground or other surfaces.

Table P.1 – Reference list of tests *(concluded)*

	String insulator units		Insulator sets	Line post insulators
	Long rod (Type A)	Cap and pin (Type B)		
Routine Tests				
Visual inspection	X	X	-	X
Mechanical test	X	X	-	X (h > 300 mm)
Electrical test	-	X [e]	-	-
Optional Routine Test				
Ultrasonic examination	X	-	-	-

[a] Test carried out on one short standard string or one long rod insulator

[b] Test on insulator sets for systems with $U_s \leq 245$ kV

[c] Test on insulator sets for systems with $U_s > 245$ kV

[d] Pollution performance tests are generally carried out on insulator strings without fittings.

[e] Applicable only to insulators in ceramic material (see EN 60383-1).

Q.2 Selection of insulators

In addition to the electrical and mechanical characteristics specified on the basis of the overhead line design parameters, and the factors detailed in clause Q.1, consideration should also be given to the choice of insulators for particular applications. This consideration may include:

- insulators of ceramic material or glass e.g. string insulator units of the cap and pin type or long rod type, line post insulators;
- composite insulators;
- dimensions, including length of strings or sets, spacing of individual units, diameter, creepage distance, shed profile and coupling or fixing arrangement;
- withstand voltages;
- corrosion protection e.g. galvanising of metal parts, zinc sleeves on cap and pin units, greasing of connections;
- weight of insulator units, strings and sets.

Q.3 Packing and delivery of insulators

Insulators should be packed in a manner suitable for safe delivery to site. The size and weight of individual packages should be consistent with convenient handling on site and during line construction e.g. to meet the purchaser's requirements.

The size and weight of bulk packages should be consistent with the requirements of the means of delivery and the limitations of mechanical handling.

The design of crates should give suitable protection and support to the insulator unit(s) and should as far as possible prevent impact damage or shed damage under conditions normally encountered during transportation and handling on site.

The packaging should comply with any requirements regarding disposal of packing materials.

Q.4 Precautions during installation of insulators

During installation insulators should be handled with sufficient care to avoid damage. In some cases the use of mechanical lifting equipment may be appropriate. Whether insulators are manually or mechanically lifted into position, due regard should be given to safety considerations for the personnel concerned

When lifting longer insulator strings or sets it is recommended that a cradle or other device is used to minimise bending loads and eliminate any risk of distortion of the couplings of string insulator units or damage to composite insulators.

Insulators with semi-rigid couplings (e.g. clevis, tongue or eye) may suffer damage if submitted to high torsional loads. A suitable system for relieving stresses may therefore be necessary during conductor stringing operations.

Annex Q
(informative)

Insulators

Q.1 Specification of insulators

Q.1.1 Factors influencing the specification of insulators

Insulators and insulator sets for use in the construction of an overhead line are designed to meet the relevant electrical and mechanical characteristics as determined by the design parameters for the line. Additional factors relating to operation, maintenance and the environmental impact may need to be considered when specifiying the requirements for insulators and insulator sets for use in the construction of the line.

Q.1.2 Operational factors

Typical factors involved are:

- target system reliability and line restoration time for different categories of forced outage;
- required lifetime for each component;
- nominal system voltage;
- temporary over-voltages;
- insulation coordination and line switching policy;
- electrical clearances.

Q.1.3 Maintenance requirements

Typical requirements involved are:

- working practices - live line (hot line) or dead line;
- access to conductors via insulators;
- performance of damaged insulators i.e. residual strength;
- provisions for attachment of maintenance equipment on both suspension and tension sets.

Q.1.4 Environmental parameters

Typical parameters involved are:

- altitude and its effect on insulator performance;
- pollution level and type of pollution;
- constraints on audible noise level or radio interference voltage;
- lightning (lightning flash density [keraunic] level) and the extent of system protection against its effects;
- maximum and minimum ambient temperatures;
- visual amenity e.g. colour of insulators;
- vandalism.

Annex R
(informative)

Line equipment – Overhead line fittings

R.1 Specification and selection of fittings

R.1.1 Factors influencing specification and selection

Fittings for use in the construction of an overhead line are designed to meet the relevant mechanical and electrical characteristics as determined by the design parameters for the line. Additional factors relating to operation, maintenance and the environmental impact may need to be considered when specifying the requirements for fittings and in selecting particular designs for use in the construction of the line.

R.1.2 Operational factors

Typical factors involved are:

— target system reliability, security and safety and line restoration time for different categories of forced outage;
— required life time for each component;
— operating voltage range;
— current carrying capabilities;
— short circuit performance;
— constraints on electrical losses;
— stress limiting by suitable clamp design.

R.1.3 Maintenance requirements

Typical requirements involved are:

— working practices - live line (hot line) or dead line;
— access to conductors via insulators and fittings;
— provisions for attachment of maintenance equipment on both suspension and tension sets;
— access along conductors to in span fittings (e.g. spacers and visibility markers).

R.1.4 Environmental parameters

Typical parameters involved are:

— wind characteristics for vibration performance;
— constraints on audible noise level or radio interference voltage;
— vandalism;
— visibility marking for birds and aircraft;
— ambient temperature range and maximum and minimum temperatures;
— atmospheric pollution influencing corrosion protection;
— wind/ice loadings affecting strength selection.

R.2 Packing and delivery of fittings

Fittings should be packed in a manner suitable for safe delivery to the site. The size and weight of the individual packages should be consistent with convenient handling on site.

The size and weight of the bulk packages should be consistent with the requirements of the means of delivery and the limitations of mechanical handling.

The packaging should comply with any requirements regarding disposal of packing materials.

R.3 Precautions during installation of fittings

During installation fittings should be handled with sufficient care to avoid damage. In some cases the use of mechanical lifting equipment may be appropriate. Whether fittings are manually or mechanically lifted into position, due regard should be given to safety considerations for the personnel concerned.